SENSITIVITY ANALYSIS OF MODEL PARAMETERS AND APPLICATIONS OF INDO-SWEDISH TRAFFIC SIMULATION MODEL

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by

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CERTIFICATE

This is to certify that the work contained in this thesis entitled *"Sensitivity Analysis of Model Parameters and Applications of Indo-Swedish Traffic Simulation Model"*, submitted by W. Krishna Mohan Reddy in partial fulfillment of the requirements for the award of Master of Technology is a bonafide record of research carried under my supervision and guidance and that this work has not been submitted elsewhere for the award of a degree.

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ABSTRACT

The main objective of the present work is to identify the parameters in Indo-Swedish Traffic Simulation Model needing the most attention, by carrying out sensitivity analysis, and to determine the level of service conditions on a bi-directional single lane plane terrain road using the Indo Swedish Traffic Simulation model.

Model sensitivity analysis has been carried out by varying the parameters identified for the study and the effect of which is judged on the basis of their influence on the average speed of the stream. The study is confined to narrow roads (single lane and intermediate lane) on level and rolling terrains. Traffic composition is decided depending on the parameter investigated. Simulation runs are performed for different flow rates and the output is processed to get the desired output format. The relative sensitivity of the model parameters is studied at different flow rates to conclude with the results of sensitivity analysis.

Passenger Car Equivalents (PCE) of truck on a single lane plane terrain road are calibrated using a concept called vehicle throughput. The vehicle throughput of a traffic stream represents the number of vehicle kilometers, the stream has actually traveled in a unit interval of time. The Equivalent Vehicle Throughput method is used for determining passenger car equivalents. The PCE of a vehicle is treated as a quantity varying dynamically with flow, composition, etc. The level of service conditions are determined using speed and density as criteria. The variation in level of service with each incremental addition of truck in the ideal stream has also been studied. Speed and density have been used as criteria for defining the level of service.

Also the effect of incremental addition of trucks to Maruti Car Stream is studied on acceleration noise, shoulder usage in the form of average shoulder speed and number of passings highlighting the ease with which they can be evaluated using simulation which otherwise are very difficult to be collected in the field.

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CHAPTER 1

Introduction

1.1 General

Road transport plays a significant role in India's transportation system and is a vital sector in the country's economy. With traffic on Highways increasing, the demand for upgrading the roads from their existing status has exerted substantial pressure on planners. In order to select most beneficial schemes from among a number of proposals, it is necessary to have an economic appraisal of various alternatives. Rational decisions will be required before undertaking such projects. This necessitates the ready availability of reliable information regarding capacity and operational conditions of the existing and proposed facilities.

1.2 The Road and Traffic Scenario in India

Indian highway system consist primarily of single lane, intermediate lane two lane and four lane undivided and divided carriageways. Road length having more than four lanes are negligible. In rural areas single lane roads which have a pavement width of about 3.75m are predominant. The roads with pavement of 5.5m wide are known as intermediate lane roads and that of 7m wide are the two lane highways. The four lane divided carriage way roads are 14m to 15m in width, and are provided with a median barrier. In general all the roads are provided with earthen shoulders. Some times part of the shoulders of the single lane roads have been improved with brick paving to increase the effective width of the roads to facilitate the ease of movement of the vehicles. The brick paving varies in width from about 0.5m to 2.0m. These shoulders play a very important role during crossing and passing maneuvers. According to the updated Road User Cost Study (RUCS) [10], good paved shoulders can increase the capacity of the road by about 20 to 30 percent. Realizing the need for good shoulders, the Indian Roads Congress (IRC) [4] recommends that good quality shoulders such as moorum shoulders be provided, on all types of roads.

The road traffic on Indian road network is highly heterogeneous, being constituted by vehicle types as fast as Maruti cars and as slow as bullock carts. The fast moving vehicles include light commercial vehicles, cars, trucks, buses and several other categories of two wheelers. Among the slow moving vehicles, bicycles, cyclerickshaws and animal drawn vehicles dominate the scene.

1.3 Need for Capacity Analysis of Indian Roads

One of the main reasons for growth of congestion on Indian Highways is that the growth of traffic has outpaced the growth of highway network. The total length of National Highways increased only by about 70 % between 1950-51 and 1989-90 while the increase in all other roads (State Highways, District roads and Village roads etc.,) is of the order of 544 %. Also in 1950-51, only 39 % of the total road length was surfaced. This rose to 43.3 % in 1970-71 and 46.7 % in 1984-85 respectively. The latest available information does not indicate any significant increase in the proportion of surfaced roads. The total number of all types of motorized vehicles increased from a mere 3 lakhs in 1950-51 to 192 lakhs in 1989-90 [8], which is of the order of 6300 %. If we compare the above mentioned percentages, the increase in road congestion is explained and the need to upgrade the road network gets reinforced.

Information regarding the capacity and level-of-service on an existing road is very important for upgrading that road. Unlike the western countries where extensive research has been done in this field and where procedures for capacity analysis exist for each and every type of highway facility, comparatively little work has been done in this field in India. Except for the guidelines for capacity analysis on urban and rural roads, which the IRC publishes from time to time, the transportation planner in India has little to choose from. No methodologies have been prescribed for the capacity analysis of Indian roads and the existing guidelines are based solely on the speed-flow relationships established in RUCS[10]. The very fact that only two parameters i.e., the speed and flow, have been the basis for determining capacities right from the single lane roads to four lane divided carriageways, prompts for extensive studies on capacity analysis of Indian roads.

1.4 Role of Simulation in Traffic Engineering

The complexity of modern traffic system management strategies often require that predictive modeling studies be conducted prior to the implementation of any strategy. Two basic approaches used for traffic modeling are analytical and simulation. Analytical models attempt to obtain solution by means of a single equation, or a limited number of equations. Thus their use is confined to simple traffic engineering problems. Simulation models on the other hand attempt to find solution by means of sequential and iterative application of equations and inequalities. Therefore, their applications are extended normally to the complex situations of traffic systems where a large number of variables and constraints play significant role.

Simulation has been recognized since long as a powerful problem solving technique. Apart from the advantage cited above the following facts also favour simulation of traffic operations:

- Simulation of complex traffic operations may provide an indication of which variable is important and how they relate. This may later lead to successful analytical formulation.

- Simulation is cheaper than many forms of experiment. It offers the opportunity for the investigator to collect as much data as is needed for the meaningful inference to be drawn from the results. This reduces the difficulties of collecting huge amounts of field data.

- Simulation gives an intuitive feeling for traffic system being studied and is therefore instructive.

Thus we can say that a properly modeled and thoroughly validated simulation model can represent realistically highly complex traffic systems. Hence the present work focuses on sensitivity analysis of some of the model parameters to have a better insight into future structure of the model and the application of the Indo Swedish Traffic Simulation Model for the capacity analysis of single lane roads.

1.5 Statement of the Problem

Since considerable amount of effort has been spent in structuring the logic for Indian roads and traffic conditions and for Calibration and Validation of the Model, it is only natural to consolidate the gains. Thus the logical extension to the earlier work on the Indo Swedish Traffic Simulation Model will be to proceed with a sensitivity analysis of various parameters involved in the model.

In the first phase, some model parameters and decision thresholds have been calibrated in the light of the simulation results during the validating exercises. Tests for sensitivity of these parameters in simulation results are to be investigated in depth so as to get insight into the development of future model structure.

In the second phase, keeping in view the need for capacity analysis and the universal shortage of data, for narrow roads, as explained above, it was decided that speed–flow relationships for single lane roads be studied first for ideal traffic conditions, and then the effect of each incremental addition of truck on the speed–flow relationships be investigated using the Indo Swedish Traffic Simulation Model.

A prerequisite for developing speed–flow relationships for mixed traffic conditions is the need to express the relative effect of all types of vehicles in terms of a standard vehicle, which is usually a passenger car. Hence Passenger Car Equivalents (referred to as PCE hereafter) are to be calibrated. Once PCEs are calibrated the next step is to develop speed–flow relationships for mixed traffic. The capacity of single lane roads is to be determined using the concept of vehicle throughput.

1.6 Organization of Thesis

Chapter 1, the introduction chapter gives the background to the simulation modelling study as per Indian conditions and also describes briefly the Indo Swedish simulation Model.

Chapter 2 highlights all the important concepts of the Swedish Traffic Simulation Model. Firstly all the main programs in the program system of the VTI model are explained briefly, then the road and the traffic submodel.

Chapter 3 gives a detailed description about the methodology adopted in carrying the sensitivity analysis on the selected model parameters. Results of the simulation are interpreted to identify the factors which are sensitive to changes and which require due attention in the development of future structure of the model.

Chapter 4 deals with the computation of PCE factors of trucks using the simulation model for different flows and for different composition of trucks in Maruti-Truck traffic stream. A study of smoothness/jerkiness of the flow in terms of acceleration noise is also presented in this chapter.

Chapter 5 deals with capacity analysis of Single lane road using the concept of level of service. Speed and density are used as measures of effectiveness in arriving the level of service. Use of simulation model is highlighted in the study of shoulder speed and number of overtakings/passings.

Chapter 6 presents the summary of the present work, conclusions drawn from the study and the scope for future study.

CHAPTER 2

Indo Swedish Traffic Simulation Model

2.1 History

A stochastic discrete event simulation model was developed by the Swedish National Road and Traffic Research Instate for the two lane bidirectional traffic system during the period 1965-1977 [1]. It has a long history of calibration and validation over a number of road stretches in Sweden. Subsequently the model has been used for traffic analysis in providing auxiliary lanes in Finland and the United Kingdom. While RUCS was initiated in India, the need to develop a simulation model for the Indian road and traffic conditions was felt. Accordingly, an evaluation of several models that existed in 1980 led to the conclusion that the best available and reliable model was the one developed by the VTI. This model formed the basis for work done in subsequent years at the Indian Institute Of Technology, Kanpur in collaboration with the scientists of VTI. The version of the model is currently known as the Indo Swedish Traffic Simulation Model [2].

2.2 Description of Indo Swedish Traffic Simulation Model

The traffic and road conditions prevailing in India are too complex to model by simple approaches. It is necessary to incorporate the heterogeneity of traffic and the hosts of road widths along with shoulders. The basic structure of the VTI model was such that it had built in features that allowed the restructuring of the model for Indian conditions (Gynnerstedt,1983). The program and the data structures are based on the Jackson Structured Programming (JSP) technique and has been programmed in one of the highest level simulation languages - SIMULA 67. Simula has built in features like pseudo-parallel execution that facilitates simulation of any process. The model has been calibrated and validated extensively for single, intermediate and two lane roads in India.

2.2.1 General Program Design

The program mainly consists of two processes, which also contain the data and procedures. They are

1. Process class generatorprocess
2. Process class vehicle

The vehicle generator process creates the road objects and allots the individual driver vehicle attributes. Here they are also allotted their traffic attributes. Parameters which define the vehicles are identity number, basic desired speed and power mass ratio. Parameters giving their traffic attributes are origin of the vehicle, destination of the vehicle and entry time. The vehicle generator process also activates vehicles at their starting times.

The vehicle process describes all possibilities of action that a particular vehicle can have, for example '*drive as freely moving vehicle*', '*follow another vehicle*', '*overtake the vehicle in front*' '*change to another track*', etc., The freedom of choice covers mainly the set of alternatives that any vehicle can have and the actions are assumed to occur at momentarily calculated times. At each event the model data concerned is updated and a particular event is generated from among the possible event types. A note of the predicted event is inserted chronologically and logically in a two way linked list and the events are executed in this order.

The ordinary cycle for any arbitrary vehicle is

1. Predict the time of next event -- PREDICTNEXTEVTIME
2. Wait for the predicted time -- HOLD
3. Move the vehicle in time and space -- DRIVE

During the phase one of the cycle the next event time, the time of passage of next block border, the speed from the preceding event to the next event and the predicted speed for the passage of next block border are calculated in the procedures,

PREDICTNEXTEVTIME, PREDICTBLBORDERTIME, AVERSP and PREDICTBLBORDERSP. During phase three of the cycle the procedure DRIVE updates the attributes LOCALTIME (*time of preceding event*), LOCALCOORD (*Road coordinate at preceding event*), AVERSP, PREDBLBORDERTIME, PREDICTBLBORDERSP.

During phase three of the cycle it may so happen that an adjacent vehicle or an oncoming vehicle interacts with the current vehicle with the result the predicted time of the next event for this vehicle is shown incorrect as it will occur earlier. Thus, its ordinary cycle is interrupted and the current vehicle considers that a surprise has occurred through the procedure SURPRISE. The prediction of the new event time for a vehicle is then made.

2.3 Program System

The various subsystems of the entire program system and their linkages are represented in the Fig 2.1. Simulation program is the heart of the system.

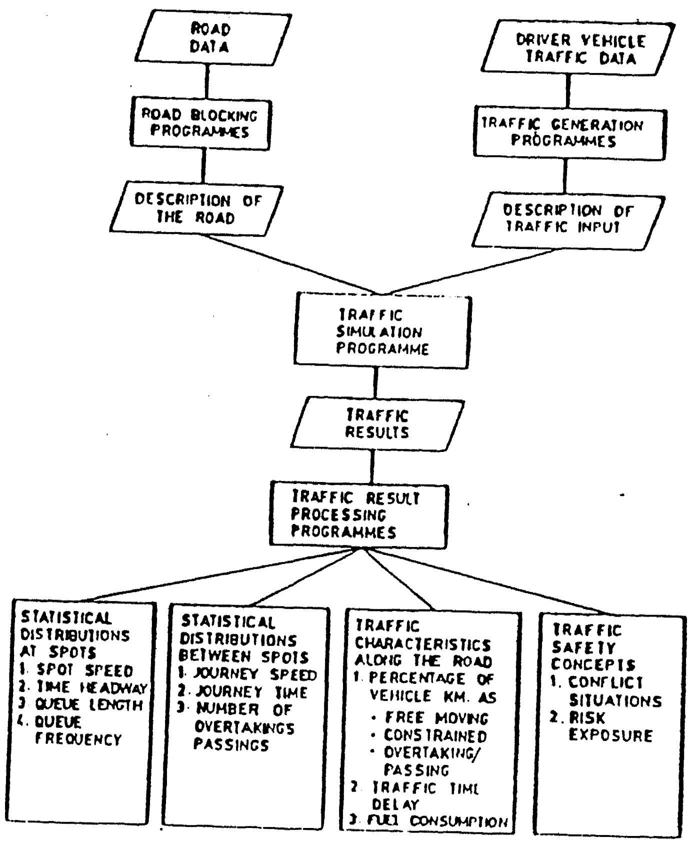


Fig 2.1 Program System for Traffic Simulation

2.3.1 Road Blocking Program

This program generates the road description as needed for the simulation program. Using the road geometry and traffic regulation data, the road is divided into homogeneous blocks. The minimum and maximum length of a block can be specified by the user. The sight distance break points are also calculated in this program.

2.3.1.1 Track or Lane Classification

The model divides the road width into the following three tracks or lanes in each direction of travel as shown in the Fig 2.2.

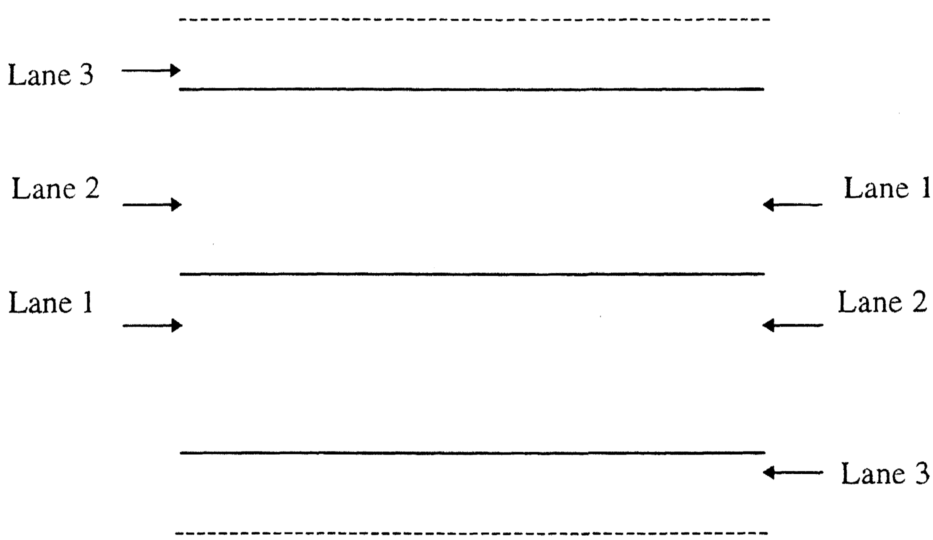


Fig 2.2 Classification of Tracks or Lanes in the Model

Lane No.1: The wrong lane of travel (*A overtaking vehicle occupies this track during lane change in overtaking operations)*

Lane No.2: The usual lane of travel of a vehicle

Lane No.3: Represents shoulders or extra lanes (*This lane is used by the vehicle when yielding to a faster vehicle from behind and during crossing impedance)*

2.3.2 Traffic Generation Program

This subsystem generates the traffic for the simulation model. Traffic input for each vehicle is given in the form of vehicle identification, entry time on the road stretch, direction of travel, entry speed, basic desired speed and power weight ratio. This input is derived either from the observed traffic data or through traffic generation program .

Traffic generation program uses the parameters like

- Total flow
- Flow in each direction
- Traffic composition
- Total time of simulation

2.3.3 Traffic Simulation Program

This is the heart of the entire system. It takes as input the road description and traffic description as obtained from the first two subsystems. The road is divided into homogeneous sections termed as "*block*" with respect to road width, speed limit, horizontal curvature, gradient and overtaking restrictions. A change in any of these factors marks the beginning of a new block.

Vehicles interact with each other as they move over the road sections. A vehicle is said to be interacting with surrounding vehicles when its behavior is affected by another vehicle or group of vehicles. Interaction of vehicles in traffic with each other constrains them from moving at the desired speed of each vehicle.

The simulation process is based on the event scanning principle. The events are scanned in chronological order and at each new event, the model data concerned is updated. The status of the vehicle is updated at the end of every event.

2.3.4 Traffic Results Processing Program

The traffic results obtained from the simulation model are analyzed in this subsystem to obtain

- Statistical distributions of various measures of effectiveness that can be used for validation and sensitivity analysis
- Description of traffic along the road which can be used for determining many of the traffic parameters like acceleration noise, density, number of overtakings, speed on the shoulder etc.,

2.4 Road Submodel

The logic adopted here is that the traffic is prevented from maintaining its basic desired speed by the following factors

- Road width less than 12 m.

Here it is assumed that the roads over 7m width are built with carriage way and the remaining width consists of two hard shoulders. For road widths less than 12m, the median basic desired speed, V_{0m}, is reduced to median speed V_{1m}.

- Curves with radius less than 1000m.

The curves with radius more than 1000 m do not effect the median speed V_{1m}. If, however the radius is less than 1000 m, the median speed, V_{1m}, is further reduced to V_{2m}.

- Effect of surface roughness

In the presence of surface roughness the median speed V_{2m} is further reduced to V_{3m}.
For each vehicle the speed is determined based on the first three factors and the effect of gradient is then superimposed to obtain the free speed. After the median speed V_{3m} is

calculated the resulting free speed distribution of ν_{3m} is calculated using a transformation measure as explained in the next section.

2.4.1 The Transformation Measure

The transformation measure Q indicates how far the basic desired speed must be rotated about the median speed V_{3m} for free speeds. Thus, Q value is function of median speeds V_{0m}, V_{1m}, V_{2m}, V_{3m}. The free speed distribution ν_{3m}, is determined using Q value transformation as follows

$$\nu_{0i}^{\ Q} - \nu_{3i}^{\ Q} = V_{0m}^{\ Q} - V_{3m}^{\ Q}$$

where ν_{0i} and ν_{3i} are speeds at any arbitrary percentile i in the basic desired speed and free speed distributions.

If Q value is equal to one, then the above equation results in purely parallel shift indicating a constant reduction in speed for fast as well as slow moving vehicles.

However when Q value is less than one the free speed distribution ν_{3m} is rotated anticlockwise direction showing that a driver with a higher BDS reduces his speed more than a driver with a lower BDS when influenced by speed reduction factors. It must be noted that smaller the value of Q the larger will be the rotation indicating that the driver with higher BDS reduces his speed drastically due to speed reduction factors than the driver with low BDS.

2.5 Traffic Sub model

This model assigns the vehicle characteristics as well as traffic characteristics (starting point, starting time and destination). The distributions of the vehicles among the various classes, i.e., cars, trucks, scooters etc., is to be specified in the input data. Some of the procedures for generating the vehicles and traffic parameters are explained below.

Identification number: This is trivially generated by incrementing each time a vehicle is generated to enter a simulated road stretch at the specified coordinate.

Vehicle type: The vehicle type of individual vehicle is obtained from the distributions specified for the anticipated traffic composition.

Basic desired speed: The vehicles are uniformly distributed over the basic desired speed distribution for each vehicle type as specified in the input.

Power to mass ratio: The power equation is obtained by considering the various forces acting on the vehicle such as the air resistance, rolling resistance, gravitational force induced due to gradient and the tractive force at the wheels.

Entry time: The entry time for each vehicle entering the simulated road stretch is generated using the Shchul's (1955) composite time headway model.

The usual form of the composite distribution is

$$f(t) = (1-\alpha) * g(t) + \alpha * h(t)$$

Where

$f(t)$ is the probability density function of the composite headway distribution.

$g(t)$ is the density function for headway distribution of free moving vehicle.

$h(t)$ is the probability density function for constrained vehicles.

α is the proportion of constrained vehicles.

Entry speed: This is taken as follows.

$0.85 * BDS$ if vehicle is free

$0.85 * (BDS)_{minpl}$ if vehicle is constrained, where $(BDS)_{minpl}$ is the minimum BDS among a platoon of vehicles.

However, these speeds are constantly reassessed once the vehicle enters the road stretch to be simulated. Hence the entry speeds assigned are comparatively less important.

2.6 Interactions on Narrow Roads as Dealt by the Simulation Model

2.6.1 Passing Maneuver

The restrictions of road width imposed by narrow roads tend to inhibit and limit the overtaking interactions. Hence in the simulation model it is assumed that no overtaking is possible on the single and intermediate lane roads. A faster vehicle can only pass a slower moving vehicle if the later yields space by moving partly to the shoulder. Thus the passing maneuver is due to the following factors:

- Vehicles on narrow roads generally tend to move on the middle of the carriageway.
- The restriction of road width due to which a faster vehicle cannot actually move to a wrong lane to pass the slow moving vehicle.
- The inclination of the driver of the leading vehicle to yield space that is a random variable.

The Fig 2.3 describes the passing maneuver as performed in the simulation program. The simulation program assumes that a slow moving vehicle yields space and moves to shoulders with a certain probability called *'lane3 probability'*.

2.6.2 The Crossing Maneuver

So far as the meeting and crossing interactions are considered, they are not only unavoidable but also involve greater degree of interaction which increases with the reduction in road width.

2.6.3 The Transformation Measure for Crossing Speeds

As mentioned in section 2.4.1 the basic desired speed is reduced to median speed V_{3m} when influenced by road width, horizontal curvature and surface roughness. This median speed V_{3m} is further reduced to V'_{3m} under the influence of crossing impedance. The

transformation measure for crossing speeds, CQ value, is an index which shows the trend in the reduction of speeds during crossing maneuvers for vehicles moving at a higher BDS to that moving at lower BDS.

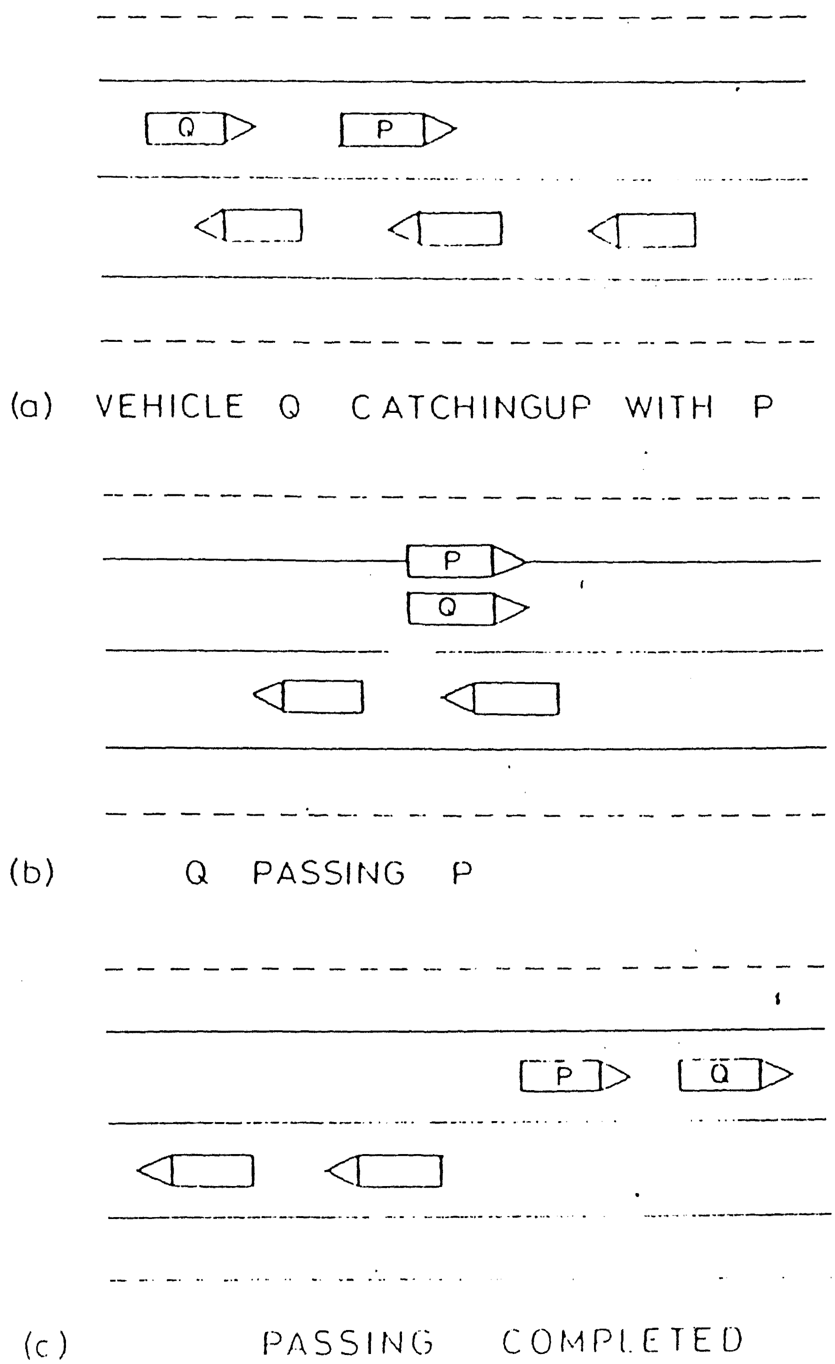


Fig 2.3 Passing Maneuver described in Indo-Swedish Traffic Simulation Model

On every road block, the free block crossing speed is calculated using the following equation

$$\text{Free block crossing speed} = (VON^{CQ} + CVQ)^{1/CQ}$$

Where,

VON is the basic desired speed. This basic desired speed is obtained from the BDS distribution of the vehicle from traffic file.

CQ is the measure of rotation which indicates how far the crossing speed distribution is shifted because of the effect of crossing maneuvers.

and

$$CVQ = V'_{3m}{}^{CQ} - V_{0m}{}^{CQ}$$

Where ,

V'_{3m} is the median block crossing speed which is obtained on superimposing the effect of crossing impedance in the median block speed V_{3m}.

V_{0m} is the median basic desire speed.

Thus the CQ value is a very important parameter in the simulation program. CQ values have been calibrated for different types of vehicles involved in crossing, on both plain and rolling terrains, and for both single and intermediate lane roads [11].

CHAPTER 3

Sensitivity Analysis of Model Parameters

3.1 Introduction

Indo-Swedish model has been successfully validated for Indian road and traffic conditions. The original two lane bi-directional traffic simulation model system aimed for simulation of homogeneous motor traffic in Sweden has been generalized with regard to heterogeneous road traffic in India. The model system now includes slow moving non motorized traffic and has been extended to cover a larger range of roadwidths and traffic conditions.

3.2 Calibration and Validation of the Model

For the calibration and validation of the simulation model for different road widths and terrain conditions for heterogeneous traffic, real time traffic data has been collected on eight road stretches covering level and rolling terrain conditions. The model has been calibrated separately for each type of terrain and is validated [18].

The validation of the model is convincing. Thus the ability of mirroring the heterogeneous traffic conditions ruling in India (for narrow roads) by applying traffic simulation technique has been successful. The calibrated constants for different types of road stretches are presented in Table 3.1

3.3 Need for Sensitivity Analysis

Since considerable amount of effort has been spent in structuring the logic for Indian roads and traffic conditions, it is only natural to consolidate the gains achieved thus far in this research. Thus the logical extension to the earlier work will be to proceed with a thorough sensitivity analysis of various parameters involved in the model.

In the first phase, some model parameters and decision thresholds have been calibrated in the light of the simulation results during the validation exercise. Tests for sensitivity of

these parameters in simulation results are to be investigated in depth so as to get an insight into the development of future model structure.

Table 3.1 Calibrated Constants for Different Types of Road Stretches

Vehicle Type	Single Lane Plane Terrain	Intermediate Lane Plane Terrain	Rolling Terrain
Ambassador	0.85	1.13	1.22
Fiat	1.00	1.18	1.00
Maruti	0.84	1.11	1.06
Jeep	1.16	1.21	1.22
Scooter	1.09	1.15	1.10
Matador Van	1.17	1.14	1.12
Bus	0.58	0.81	1.00
LCV	1.00	1.17	1.17
Truck	0.78	0.83	1.15
Tractor	1.00	1.00	1.00
Tempo	0.81	1.00	0.88

3. 4 Scope for Sensitivity Analysis

The scope for the present work is to identify the parameters affecting the simulation model and needing the most attention. Parameters to be recalibrated should depend on how much influence the parameter has on the simulation output. Model sensitivity analysis has been carried out by varying most of the parameters and the effect of which is judged on the basis of their influence on the output.

The parameters requiring the sensitivity analysis are of two types. Firstly, there are a number of parameters calibrated for the free speed modeling some of which have already been subjected to sensitivity tests during the earlier phase of the simulation research and at later stages. These parameters are used to account for the effect of road width, curvature and speed limit on the free speed distribution. These variables which affect the free speed have their own measure of rotation q_i in the VTI model terminology. The final rotation parameter was obtained by using weights k_1, k_2 and k_3. These weights have been arrived at by a number of trail error runs of simulation runs with extensive tests on the road sub model.

Secondly, there are probability distributions for the various characteristics of each vehicles type. The distributions which need the analysis are yielding probabilities, basic desired speed distribution and power weight ratio distribution. Apart from these, some of the constants used in the model also require detailed analysis. Some of them are track 3 speed reduction (speed reduction factors when using shoulders), crossing- head length, tail length and deceleration rates of individual vehicles.

Thus the parameters/factors identified for sensitivity analysis are

1. Congestion effect and yielding probabilities
2. Impedance due to slow moving vehicles
3. Deceleration rates
4. Power weight ratio distribution
5. Track 3 speed reduction
6. Basic Desired Speed distribution

3.5 Implementation Methodology

3.5.1 Congestion Effect and Yield Probabilities

Congestion is a result of increased flow of vehicles and heterogeneity of the traffic flow. As the traffic mix considered is a combination of different vehicle types including slow as well as fast moving vehicles, only amount(volume) of flow of traffic is the factor influencing the congestion. Increased flow results in greater number of interactions between the vehicles and decreased headways as a result of which speed of fast moving vehicles is reduced drastically. Another notable feature to be taken note of in this process of is the decreasing lane 3 probabilities (yielding probabilities) which is accounted for the preoccupation of lane 3 by the slow moving vehicles which leave little space for fast moving vehicles. Following are the features of implementation of sensitivity analysis to combinedly access the effect of flow (congestion) and yielding probability.

1. Three road stretches have been selected with different widths and terrain conditions
   a) Single lane plane terrain
   b) Intermediate lane plane terrain

c) Rolling terrain

The geometrics of these roads are listed in the Table 3.2 below.

Table 3.2 Geometrics of different road stretches

	SLPT	ILPT	ROLL
Width (m)	4.0	5.6	3.7
Length (m)	5000	5000	4760
Average Gradient (%)	0	0	2.54
Roughness (mm/km)	5000	5000	5385
Limiting Speed (km/hr)	50	70	50

2. The traffic mix used for different terrain conditions is shown in the Table 3.3 below

Table 3.3 Traffic Mix on different Roads (in percent)

S.No.	Vehicle Type	SLPT	ILPT	ROLL
1	Ambassador	5	15	5
2	Fiat	5	5	5
3	Maruti	10	20	20
4	Jeep	15	5	5
5	Scooter	15	15	40
6	Matador Van	5	0	0
7	Bus	10	10	10
8	LCV	5	5	0
9	Truck	15	10	10
10	Tractor	5	5	0
11	Tempo	5	5	5
12	Horse cart	3	3	0
13	Bullock cart	2	2	0

3. Traffic is generated for different flows for two cases:

Case1: For a lane 3 probability of 1.0 for all the vehicles irrespective of the amount of flow

Case 2: For a lane 3 probability depending on the amount of flow, whose values are given in Table 3.4 below

Table 3.4 Lane 3 Probabilities for Different Flow Rates

Flow (veh/hr)	Lane 3 Probability
Less than 101	1.0
101 - 200	0.8
201 - 300	0.6
301 - 400	0.4
401 - 500	0.2
Greater than 500	0.0

The results of the simulation are shown in Tables 3.5 to 3.7 and represented in Figs 3.1 to 3.3.

3.5.1.1 Interpretation of Results

1. Model is sensitive to the congestion effect (flow rates) which can be seen from the decreased speeds of vehicles with increase in flow of traffic with a constant lane 3 probability of 1.0 for all vehicles (Case 1) throughout. The maximum decrease in speed for single lane plane terrain is at flow of 500 veh/hr showing a change of 6.3 km/hr from a maximum speed of 40 km/hr attained at a flow of 200 veh/hr. Where as the maximum decrease in speed for intermediate lane plane terrain and rolling terrain are 6.4 km/hr and 1.2 km/hr respectively.

2. Model is very sensitive to the lane 3 probabilities as the decrease in speeds is more pronounced in case 2 i.e., decreasing lane 3 probabilities with increase in flow of traffic. The maximum decrease in speeds for single lane plane terrain, intermediate lane plane terrain and rolling terrain roads are 24.6 km/hr, 25.7 km/hr and 2.6 km/hr respectively.

3. As can be seen from the results that the models for plane terrain roads are more sensitive to the lane 3 probabilities than the model for rolling terrain.

4. The calibration of yield probabilities should be given atmost importance in the next stage of restructuring of the model. Sufficient data is to be collected to accomplish this task.

3.5.2 Impedance due to Slow Moving Traffic

Traffic flow patterns on Indian roads is quite complex in nature. Variations in dimensions of different types of vehicles significantly affect the process of overtaking, yielding and crossing. The available road space is occupied by both slow and fast moving vehicles. The presence of slow moving vehicles especially bicycles and animal drawn vehicles generates a large amount of side friction. Wider slow moving vehicles such as horse carts and bullock carts create greater impedance on traffic than narrow vehicles such as bicycles and scooters. Due to narrow road widths and heavy traffic, faster vehicles need to overtake and cross a large number of times per unit length of road compared to relatively homogeneous traffic on wide roads.

3.5.2.1 Implementation

Two road stretches - Single lane plane terrain and Intermediate lane plane terrain are considered for the purpose of analysis of the effect of impedance. Rolling terrain road is not considered as the number of slow moving vehicles on these roads is negligible. Two types of traffic combination is considered

Case1: Traffic mix including Bullock cart and Horse cart (5% each)

Case 2: Traffic mix with no slow moving vehicles.

The traffic mix is shown in Table 3.8 below for these two cases.

A lane 3 probability of 1.0 is used for all vehicles and traffic is generated for different flow rates. The results of the simulation are shown in Tables 3.9 to 3.10 and represented in Figs 3.4 to 3.5.

Table 3.8 Traffic Mix on different Roads

		SLPT		ILPT	
S.No.	Vehicle Type	Case 1	Case 2	Case 1	Case 2
1	Ambassador	5	6	5	6
2	Fiat	5	6	5	6
3	Maruti	10	11	10	11
4	Jeep	10	11	25	26
5	Scooter	20	21	20	21
6	Matador van	5	6	5	6
7	Bus	15	16	5	6
8	LCV	5	6	5	6
9	Truck	10	11	5	6
10	Tractor	5	6	5	6
11	Tempo	0	0	0	0
12	Horse cart	5	0	5	0
13	Bullock cart	5	0	5	0

3.5.2.2 Interpretation of Results

1. There has been a considerable increase in speeds of the individual vehicles and also in the average speed of the traffic stream in case 2 (i.e., without slow moving vehicles in the traffic stream). The maximum increase of speed is at flow of 400 veh/hr whose values are 24.5 % and 12.1 % for single lane plane terrain and intermediate lane plane terrain roads respectively.

2. The increase in speeds is more pronounced (24 %) in the case of higher flow rates for single lane roads. This is because of the increased interactions with slow moving vehicles is significant at higher flow rates. It only indicates the sensitivity of side friction in deciding the speed of the stream.

3. There is a significant increase of speed for intermediate lane plane terrain roads at higher flow rates (12.1%) but nevertheless the increase is less compared to single lane terrain roads. This is due to extra free space available for maneuvers in the case of intermediate lanes which facilitates the easy maneuvering of the slow moving vehicles.

4. The speed of the traffic stream stabilises for single lane plane terrain beyond the flow rates of 300 veh/hr. This can be .explained as the process of platooning of vehicles before reaching the capacity conditions.

5. It is observed that there is no significant change of speeds in case of slow moving vehicles as the flow increases. This is because of the reason that their speeds are already slow and they are confined to the shoulders most of the times.

3.5.3 Deceleration Rate

Fast moving vehicles in the process of catching up of the slow moving vehicles, tend to follow them until there is an acceptable opportunity of maneuvering. In this process fast moving vehicles decelerate to catch up the slow moving vehicle in the front. Deceleration is also common in crossing maneuvers for bi-directional traffic. The deceleration rates have been subjected to tests to suit the Indian traffic conditions and their values have been arrived at. The sensitivity of deceleration rates is tested by using a value of 3.0 m/s^2 for fast moving vehicles only. The table showing the old deceleration in the Indo-Swedish model and that of the new ones for which sensitivity is tested is given below.

Table 3.11 Deceleration Rates (in m/s^2)

Vehicle Type	Deceleration* Rates(case 1)	Deceleration* Rates(case 2)
Ambassador	2.5	3.0
Fiat	2.5	3.0
Maruti	3.0	3.0
Jeep	2.5	3.0
Scooter	1.0	1.0
Matador Van	1.5	3.0
Bus	1.5	3.0
LCV	1.5	3.0
Truck	1.5	3.0
Tractor	1.0	1.0
Tempo	1.0	1.0
Horse cart	0.5	0.5
Bullock cart	0.5	0.5
Bicycles	0.5	0.5

* Deceleration rate in m/s^2.

3.5.3.1 Implementation

All the three road stretches with different terrain conditions have been used to study the effect of deceleration rate. The traffic mix used for different terrain conditions is shown in Table 3.12 below.

Table 3.12 Traffic Mix (in percent) on Different Road Stretches

S.No.	Vehicle Type	SLPT	ILPT	ROLL
1	Ambassador	5	10	5
2	Fiat	0	0	5
3	Maruti	5	15	20
4	Jeep	5	5	5
5	Scooter	15	10	30
6	Matador Van	0	5	5
7	Bus	5	5	10
8	LCV	5	5	5
9	Truck	10	5	10
10	Tractor	5	0	0
11	Tempo	0	0	5
12	Horse cart	3	3	0
13	Bullock cart	2	2	0
14	Bicycles	40	35	0

A lane 3 probability of 1.0 is used for all the vehicle types and traffic is simulated for different flow rates. The results of the simulation are shown in Table 3.13 to 3.15 and represented in Figs 3.6 to 3.8.

3.5.3.2 Interpretation of Results

1. Speeds of vehicles on single lane plane terrain road have increased when compared to that of the speeds of simulation runs with the old deceleration rates(case 1). The maximum increase in speed is 15.4 % at a flow rate of 300 veh/hr. The reason for the increase of speeds on single lanes road is due to the higher number of interactions involved in this case which means that a vehicle has to decelerate many a times. Thus the higher deceleration rates allows the vehicle to slow down the vehicle in a shorter span of time.

2. There is no significant change of speeds on both intermediate lane plane terrain and rolling terrain stretches. This is because of the less number of interactions between the vehicles due to the free space available for maneuvering.

3. Thus on single lane plane terrain roads, the vehicles with higher deceleration rates can contribute to increase of speed of the traffic steam (at higher flow rates) .

3.5.4 Power weight Ratio Distribution

The acceleration rate of vehicles on level road diminishes with speed due to various resistive forces. At lower speeds the rolling resistance is predominant, and at higher speeds air resistance is decisive in determining the acceleration of the vehicle. Air resistance often becomes a predominant factor in the case of lightly loaded vehicles, head winds, high speeds and poor streamline. Thus the power to weight ratio along with these coefficients of rolling resistance and rolling resistance determines the acceleration and thus the speed of the vehicle. In trucks and buses, power to mass ratio is lower than that of passenger cars which results in full throttle operation. It is not uncommon for a heavy truck to accelerate through the gears at full throttle.

Table 3.16 gives the power weight ratio distribution of the different vehicles used in the simulation model. The distributions have been calibrated by measuring spot speeds and time of travel on the upward gradient knowing the length and height of the gradient.

Now that there are new generation of vehicles coming up with significantly higher power, it is worth while to see the effect of these vehicles on the speeds of the traffic stream.

3.5.4.1 Implementation

As there is a greater opportunity for the fast moving vehicles of the new generation to accelerate more on the plane terrain roads using their higher power mass ratios, it has been decided to study their effect on single lane plane terrain and intermediate lane plane terrain roads. The traffic mix used on these roads is shown in the Table 3.17.

Using the above traffic composition, traffic is generated for two cases:

case 1: Old Power Weight Distribution shown in Table 3.16

case 2: New Power Weight Distribution in which Power Weight ratios are double that of the old ones for fast moving vehicles.

Table 3.16 Power Weight Distributions

Power to Mass Ratio	1	2	3	4	5	6	7	8	9	10	11
0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00	4.00	1.00
1.0	0.00	0.00	0.00	0.00	17.00	0.00	0.00	40.00	0.00	60.00	40.00
2.0	0.00	0.00	0.00	0.00	82.00	0.00	0.00	67.50	0.00	92.00	67.50
3.0	0.00	0.00	0.00	0.00	95.00	1.54	0.00	88.00	0.00	96.00	88.00
4.0	0.00	0.00	5.31	6.94	97.00	8.47	0.00	98.00	0.00	100.00	98.00
5.0	0.00	0.00	23.89	19.44	100.00	20.77	0.00	100.00	0.00	100.00	100.00
6.0	0.00	0.00	39.82	38.89	100.00	42.31	0.00	100.00	0.68	100.00	100.00
7.0	5.81	0.00	47.79	66.67	100.00	56.92	0.00	100.00	15.54	100.00	100.00
8.0	13.95	1.27	64.60	69.44	100.00	68.46	0.00	100.00	39.86	100.00	100.00
9.0	25.28	8.86	76.99	77.78	100.00	75.38	1.53	100.00	62.16	100.00	100.00
10.0	48.84	15.19	88.50	81.94	100.00	83.85	9.16	100.00	81.08	100.00	100.00
11.0	67.44	27.85	93.81	86.11	100.00	92.31	26.72	100.00	87.84	100.00	100.00
12.0	80.23	45.57	97.35	88.89	100.00	96.15	51.55	100.00	95.95	100.00	100.00
13.0	90.70	56.96	98.23	90.74	100.00	100.00	67.94	100.00	99.32	100.00	100.00
14.0	97.67	70.89	98.68	94.44	100.00	100.00	76.34	100.00	100.00	100.00	100.00
15.0	100.00	78.48	99.12	96.29	100.00	100.00	88.55	100.00	100.00	100.00	100.00
16.0	100.00	82.28	100.00	100.00	100.00	100.00	96.18	100.00	100.00	100.00	100.00
17.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
18.0	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Table 3.17 Traffic Mix (in percent)

S.No.	Vehicle Type	SLPT	ILPT
1	Ambassador	5	5
2	Fiat	5	5
3	Maruti	10	10
4	Jeep	10	25
5	Scooter	20	20
6	Matador Van	5	5
7	Bus	15	5
8	LCV	5	5
9	Truck	10	5
10	Tractor	5	5
11	Tempo	0	0
12	Horse cart	5	5
13	Bullock cart	5	5

The results of the simulation are shown in Tables 3.18 to 3.19 and also in Figs 3.9 to 3.10.

3.5.4.2 Interpretation of Results

1. It can be observed from the results that there is no increase in mean speed of the traffic stream with increased power mass ratios. Infact the speeds are less (though by a very small amount) in case 2 which may be accounted for the randomness involved in the model.

2. It can be inferred that the power weight ratio distribution is not sensitive on its own. It depends mainly on the road condition, limiting speed on that road and on the traffic composition along with the flow rate. Vehicles with higher power weight ratios do not have any real chance to accelerate and to overtake the slow moving vehicles due to the narrow widths and higher number of interactions. Power weight ratio distribution thus can be sensitive on multilane roads with sufficient free space for maneuvers.

3.5.5 Track 3 Speed Reduction

Track 3 speed reduction is the reduction applied to the speed of the vehicle when it yields by moving to the shoulder to allow the vehicle catching up from behind to overtake. This reduction factor is based on the speed of the current vehicle along with the factors listed below.

1. Speed of the vehicle catching up
2. Width of the current vehicle
3. Shoulder condition and its width
4. Width of the road

But the fast moving vehicles are expected to travel for a long time on track 3. It is a matter of time when they again start accelerating after the maneuvering operation is complete and tracks back to lane 2. Thus it is interesting to see the impact on speeds of vehicles, when track 3 speed reductions are applied whose values are greater than earlier ones used in the Indo-Swedish model.

3.5.5.1 Implementation

Plane terrain road stretches are selected for the purpose of analyzing the effect of Track 3 speed reduction. Traffic mix used on these roads is shown in Table 3.20

Table 3.20 Traffic Mix (in percent)

S.No.	Vehicle Type	SLPT	ILPT
1	Ambassador	5	5
2	Fiat	5	5
3	Maruti	10	10
4	Jeep	25	25
5	Scooter	20	20
6	Matador Van	5	5
7	Bus	5	5
8	LCV	5	5
9	Truck	10	10
10	Tractor	5	5
11	Tempo	0	0
12	Horse cart	3	3
13	Bullock cart	2	2

Case 1: Reduction factors as in Indo-Swedish model

Case 2: Reduction factors for which sensitivity is tested.

The reduction factors in case 2 are multiplying factors to the speeds of the vehicles as they take the lane 3. These factors are again dependent on the speed of the vehicle on lane 2 before shifting to lane 3. For fast moving vehicles a factor of 0.65 is used if the speed is above 8m/s and 0.85 if speed is less than 8m/s and for slow moving vehicles a factor of 0.85 is used irrespective of the speed as their initial speed is itself low and they are not expected to slow down very much.

A lane 3 probability of 1.0 is used for all types of vehicles and traffic is simulated for different flows, the results of which are tabulated in Table 3.21 to 3.22 and in Figs 3.11 to 3.12.

3.5.5.2 Interpretation of Results

1. It is observed that on single lane and intermediate lane plane terrain roads there is a very small decrease in speeds (1.4% and 1.1 % respectively) of vehicles at a flow rate of 200 veh/hr. Beyond the flow of 200 veh/hr there is an increase in speed of the traffic stream. This is because the fast moving vehicles seldom occupy track 3 at higher flow rates as it is most of the time used by the slow moving vehicles.

2. Track 3 speed reduction factor is sensitive to changes and can be considered to detailed calibration depending on the speed of the vehicle when it decides to shift to track 3. Thus sufficient data is required to arrive at the these factors reflecting the slow and mixed traffic on Indian roads.

3.5.6 Basic Desired Speed

Each vehicle/driver adopts a strategy which attempts to maintain a safe and comfortable upper limit to the speed on an ideal roadway having no restrictions on geometry, road surface conditions and other vehicular unit. This upper limit on speed is termed as basic desired speed. It involves randomness in the form of characteristics of driver and also that of vehicle.

In order to represent the traffic speed distribution in a realistic manner, a 50 percentile median distribution of basic desired speeds of each vehicle type is adopted separately in the Indo-Swedish traffic simulation model.

The basic desired speeds for the new generation of fast moving vehicles are higher than that of their older versions. Thus the effect of these vehicles with higher BDS on the traffic stream can be studied using the simulation model.

3.5.6.1 Implementation

Plane terrain road stretches are selected to study the impact of higher BDS of vehicles. The traffic mix used for this purpose is shown in Table 3.23

Table 3.23 Traffic Mix (in percent)

S.No.	Vehicle Type	SLPT	ILPT
1	Ambassador	10	15
2	Fiat	0	0
3	Maruti	10	20
4	Jeep	10	10
5	Scooter	20	15
6	Matador Van	0	5
7	Bus	10	10
8	LCV	10	10
9	Truck	15	10
10	Tractor	10	0
11	Tempo	0	0
12	Horse cart	3	3
13	Bullock cart	2	2

Traffic is generated for a flow of 100 veh/hr and 200 veh/hr for two cases on each road stretch. Sensitivity is being tested only for low flow rates as it is more likely that the vehicles can be able to move freely very close to their basic desired speeds only in the ideal conditions of straight road as less traffic.

Case 1: Basic Desired Speeds as used in the Indo-Swedish model.

Case 2: Basic Desired Speeds whose values are 50% higher than that of earlier ones for faster vehicles alone.

The results of the simulation are shown in Table 3.24 to 3.25 and in Figs 3.13 to 3.14.

3.5.6.2 Interpretation of Results

1. It is observed that on single lane plane terrain road there is no significant increase in speeds of vehicles even after increase in BDS by 50%. Infact the speeds have decreased by 0.9 % which is very small. The reason for the insensitivity of BDS on single lane road can be attributed to the inconducive road conditions in the form of narrow widths and limiting speeds which results in decrease in capacity of the road.

2. It can be seen that there is an increase of speed (0.4 % at a flow rate of 200 veh/hr) on intermediate lane plane terrain road though the magnitude is very small. Thus it is logical to study the effect of BDS on multilane roads where there is enough free space for maneuvers.

Table 3.5 Comparision of Speeds of Vehicles on Single Lane Plane Terrain for Different Lane 3 Probabilities

Flow	100 veh/hr		200 veh/hr		300 veh/hr		400 veh/hr		500 veh/hr	
Veh. Type	case 1	case 2	case 1	case 2	case 1	case 2	case 1	case 2	case 1	case2
1	42.5	42.5	42.4	42.4	35.8	29.6	39.1	19.4	35.7	14.7
2	44.6	44.6	43.5	40.5	40.9	30.0	38.5	21.4	38.9	17.7
3	48.2	48.2	47.7	46.0	42.5	32.2	44.0	24.6	41.5	16.8
4	46.0	46.0	46.3	44.6	39.1	29.6	41.2	20.9	38.2	13.4
5	45.4	45.4	44.9	43.4	39.9	31.5	38.8	20.4	38.3	15.5
6	44.4	44.4	44.2	41.8	36.3	33.1	40.4	18.2	37.0	17.1
7	38.5	38.5	37.7	36.7	32.7	30.5	33.9	20.4	34.6	14.8
8	39.4	39.4	38.8	37.8	35.4	29.7	37.3	23.4	34.1	16.6
9	37.1	37.1	36.7	35.6	34.3	27.5	33.3	20.6	31.9	15.3
10	19.5	19.5	19.2	19.2	18.8	18.5	19.2	16.7	18.3	13.9
11	30.5	30.5	30.0	29.5	26.2	21.3	26.8	15.9	26.0	11.9
All	39.2	39.2	40.0	38.7	34.9	28.2	35.2	20.0	33.6	14.6

Table 3.6 Comparision of Speeds of Vehicles on Intermediate Lane Plane Terrain for Different Lane 3 Probabilities

Flow	100 veh/hr		200 veh/hr		300 veh/hr		400 veh/hr	
Veh. Type	case 1	case 2	case 1	case 2	case 1	case 2	case 1	case 2
1	51.0	51.0	49.6	44.4	45.8	38.8	44.1	20.6
2	Inss	Inss	55.3	49.8	51.1	43.2	51.8	17.8
3	58.6	58.6	57.1	50.4	55.0	40.9	46.8	19.7
4	53.1	53.1	52.6	50.4	45.1	39.5	41.9	16.8
5	44.2	44.2	44.0	41.4	41.1	35.3	38.8	19.7
6	-	-	-	-	-	-	-	-
7	37.0	37.0	36.9	34.4	35.9	32.2	34.2	20.2
8	47.1	47.1	46.5	45.8	41.7	37.5	40.1	24.4
9	32.9	32.9	32.9	30.9	31.9	29.9	30.3	16.6
10	20.8	20.8	20.4	20.6	20.1	19.1	20.3	16.3
11	Inss	Inss	29.7	29.7	28.3	21.9	26.2	13.4
All	44.5	44.5	45.4	41.7	42.5	35.4	39.0	18.8

Table 3.7 Comparision of Speeds of Vehicles on Rolling Terrain for Different Lane 3 Probabilities

Flow	100 veh/hr		200 veh/hr		300 veh/hr		400 veh/hr		500 veh/hr	
Veh. Type	case 1	case 2	case 1	case 2	case 1	case 2	case 1	case 2	case 1	case 2
1	Inss	Inss	48.4	48.1	47.3	44.7	46.7	41.8	46.2	38.9
2	40.2	40.2	40.2	40.0	39.6	39.3	38.9	38.6	39.3	38.2
3	47.2	47.2	46.5	46.5	45.9	44.2	45.7	42.5	45.0	38.9
4	Inss	Inss	45.5	45.2	44.2	43.2	44.4	41.8	43.0	39.0
5	37.1	37.1	37.2	37.1	37.1	36.7	36.9	36.5	37.2	35.9
6	-	-	-	-	-	-	-	-	-	-
7	37.3	37.3	37.2	37.2	36.6	36.4	36.6	36.1	36.1	35.3
8	-	-	-	-	-	-	-	-	-	-
9	40.3	40.3	39.9	39.7	39.2	38.8	38.8	37.6	38.1	36.0
10	-	-	-	-	-	-	-	-	-	-
11	Inss	Inss	25.9	25.9	26.1	26.2	26.6	26.6	26.3	26.3
All	39.1	39.1	40.2	40.1	39.7	38.9	39.3	37.9	39.0	36.4

Table 3.9 Comparision of Speeds of Vehicles on Single Lane Plane Terrain for Impedance of Slow Moving Vehicles

	With Slow Moving Vehicles				Without Slow Moving Vehicles			
Vehicle Type	100 veh/hr	200 veh/hr	300 veh/hr	400 veh/hr	100 veh/hr	200 veh/hr	300 veh/hr	400 veh/hr
Ambassador	34.0	33.6	32.1	29.8	34.0	34.0	33.8	33.6
Fiat	40.8	37.5	35.0	37.0	43.0	42.3	40.3	40.9
Maruti	36.9	35.5	32.2	33.9	37.1	37.3	37.0	37.3
Jeep	42.7	42.5	37.2	37.4	45.1	44.8	43.1	43.1
Scooter	37.5	33.7	31.2	31.4	37.9	37.7	36.9	37.0
Matador Van	36.6	35.9	26.1	31.2	36.1	36.1	35.7	35.7
Bus	28.1	26.3	25.0	25.0	27.9	27.8	27.6	27.8
LCV	37.1	30.1	34.2	32.8	36.7	36.6	36.1	36.2
Truck	29.8	26.4	25.4	26.8	30.4	30.1	29.7	29.9
Tractor	18.9	18.5	18.3	17.5	18.3	18.5	19.0	19.4
Tempo	-	-	-	-	-	-	-	-
Horse cart	9.1	9.3	9.6	9.5	-	-	-	-
Bullock cart	5.5	5.7	5.9	6.1	-	-	-	-
Bicycles	-	-	-	-	-	-	-	-
Combined	32.7	30.5	27.8	27.8	35.1	35.4	34.4	34.6

Table 3.10 Comparision of Speeds of Vehicles on Intermediate Lane Plane Terrain for Impedance of Slow Moving Vehicles

	With Slow Moving Vehicles				Without Slow Moving Vehicles			
Vehicle Type	**100 veh/hr**	**200 veh/hr**	**300 veh/hr**	**400 veh/hr**	**100 veh/hr**	**200 veh/hr**	**300 veh/hr**	**400 veh/hr**
Ambassador	50.8	50.7	48.1	44.7	50.8	49.5	50.0	48.6
Fiat	56.9	55.2	53.9	49.4	57.2	55.0	54.7	52.9
Maruti	58.2	55.1	54.1	48.6	57.8	57.7	55.5	54.5
Jeep	52.4	51.5	49.3	43.1	51.7	51.8	50.8	49.3
Scooter	44.8	43.2	42.4	40.3	43.8	43.8	44.0	43.1
Matador Van	46.6	45.9	42.8	41.0	45.6	45.6	45.3	45.3
Bus	36.3	36.3	35.5	34.8	34.9	35.2	35.5	34.9
LCV	45.9	44.7	43.3	41.5	45.2	45.7	45.4	44.2
Truck	33.5	32.6	31.7	30.4	33.1	32.8	32.7	32.6
Tractor	20.8	20.3	20.1	20.6	20.0	20.4	20.9	21.5
Tempo	-	-	-	-	-	-	-	-
Horse cart	9.1	9.2	9.5	9.6	-	-	-	-
Bullock cart	5.5	5.7	5.9	6.4	-	-	-	-
Bicycles	-	-	-	-	-	-	-	-
Combined	43.4	43.4	41.2	39.8	46.6	47.2	46.0	44.6

Table 3.13 Comparison of Speeds of Vehicles on Single Lane Plane Terrain for different Deceleration Rates

Flow	**100 veh/hr**		**200 veh/hr**		**300 veh/hr**		**400 veh/hr**	
Vehicle Type	**case 1**	**case 2**	**case 1**	**case 2**	**case 1**	**case 2**	**case 1**	**case 2**
Ambassador	34.0	34.0	32.5	33.9	27.6	29.7	28.6	28.7
Fiat	-	-	-	-	-	-	-	-
Maruti	38.6	38.6	36.6	37.5	35.0	36.2	32.8	33.9
Jeep	44.0	44.1	43.3	41.8	36.2	37.4	34.4	37.5
Scooter	37.9	37.9	34.1	34.5	29.2	33.1	30.2	33.9
Matador Van	-	-	-	-	-	-	-	-
Bus	28.1	28.1	27.8	28.0	23.5	26.5	24.0	25.2
LCV	36.5	36.5	34.4	36.1	27.4	35.4	29.8	32.7
Truck	30.3	30.3	30.2	29.8	24.0	27.0	24.7	27.6
Tractor	19.0	19.0	19.1	19.2	18.2	18.6	16.3	17.3
Tempo	-	-	-	-	-	-	-	-
Horse cart	9.0	9.0	9.2	9.2	9.0	9.3	9.0	8.9
Bullock cart	5.4	5.4	5.6	5.5	5.7	5.7	6.0	6.0
Bicycles	8.9	8.8	8.7	8.9	8.0	7.9	7.8	7.9
Combined*	31.6	31.6	29.9	30.2	24.7	28.5	25.5	27.6

* Combined speed with out including the speed of bicycles.

Table 3.14 Comparison of Speeds of Vehicles on Intermediate Lane Plane Terrain for different Deceleration Rates

Flow	100 veh/hr		200 veh/hr		300 veh/hr		400 veh/hr	
Vehicle Type	**case 1**	**case 2**	**case 1**	**case 2**	**case 1**	**case 2**	**case 1**	**case 2**
Ambassador	51.2	51.2	50.8	50.8	47.9	47.8	43.1	41.7
Fiat	-	-	-	-	-	-	-	-
Maruti	57.9	57.9	57.5	57.4	51.2	52.9	53.0	49.0
Jeep	52.9	52.9	53.3	53.3	49.3	51.1	41.7	44.3
Scooter	43.8	43.8	44.3	44.3	36.7	42.7	39.1	37.9
Matador Van	45.9	45.9	46.2	46.2	41.6	45.4	39.2	36.7
Bus	36.2	36.3	37.0	37.1	31.1	35.2	31.3	33.4
LCV	46.8	47.6	47.1	47.3	41.5	45.0	38.7	37.5
Truck	33.2	33.2	32.9	32.9	28.5	32.9	30.6	29.8
Tractor	-	-	-	-	-	-	-	-
Tempo	-	-	-	-	-	-	-	-
Horse cart	9.0	9.0	9.1	9.0	9.3	9.3	9.4	9.3
Bullock cart	Inss	Inss	Inss	Inss	5.5	5.5	5.6	5.6
Bicycles	14.0	14.1	14.7	14.6	11.9	11.8	10.7	10.8
Combined*	45.1	45.1	46.8	46.8	44.3	44.0	40.2	38.9

* Combined speed with out including the speed of bicycles.

Table 3.15 Comparison of Speeds of Vehicles on Rolling Terrain Road for different Deceleration Rates

Flow	100 veh/hr		200 veh/hr		300 veh/hr		400 veh/hr	
Vehicle Type	**case 1**	**case 2**	**case 1**	**case 2**	**case 1**	**case 2**	**case 1**	**case 2**
Ambassador	48.7	48.7	48.3	48.3	45.8	47.6	46.5	45.3
Fiat	40.1	40.1	40.1	40.2	39.5	39.7	39.3	39.1
Maruti	46.9	46.9	46.5	46.6	45.6	45.8	45.6	45.3
Jeep	46.0	46.0	45.4	45.6	44.1	44.0	44.1	43.7
Scooter	37.0	37.0	37.1	37.0	37.0	37.0	37.0	36.7
Matador Van	39.5	39.5	39.2	39.2	39.1	38.9	39.1	39.0
Bus	37.2	37.2	37.0	37.1	36.6	36.6	36.6	36.5
LCV	41.7	41.7	41.8	41.6	40.5	40.5	40.5	40.6
Truck	40.2	40.2	39.6	39.7	39.0	39.2	39.0	38.9
Tractor	-	-	-	-	-	-	-	-
Tempo	25.7	25.7	25.9	25.9	26.2	26.1	26.5	26.5
Horse cart	-	-	-	-	-	-	-	-
Bullock cart	-	-	-	-	-	-	-	-
Bicycles	-	-	-	-	-	-	-	-
Combined*	40.0	40.0	40.6	40.6	39.7	40.0	39.6	39.4

* Combined speed with out including the speed of bicycles.

Table 3.18 Comparison of Speeds of Vehicles on Single Lane Plane Terrain for Different Power Weight Ratios

	200 veh/hr		300 veh/hr		400 veh/hr	
Vehicle Type	**Case 1**	**Case 2**	**Case 1**	**Case 2**	**Case 1**	**Case 2**
Ambassador	40.0	33.5	38.4	32.2	38.6	32.6
Fiat	43.0	43.1	38.8	42.2	37.3	38.7
Maruti	46.1	36.7	41.2	34.8	40.6	35.8
Jeep	43.6	44.2	39.5	40.4	39.3	40.8
Scooter	43.6	38.5	39.5	36.2	37.7	35.2
Matador Van	42.9	37.1	37.5	35.0	36.1	34.8
Bus	36.8	27.2	34.0	27.3	31.7	26.9
LCV	36.6	35.7	32.4	32.4	34.4	35.6
Truck	35.6	30.3	33.9	28.3	33.6	29.4
Tractor	18.9	18.9	18.5	18.9	18.0	18.5
Tempo	-	-	-	-	-	-
Horse cart	9.4	9.4	10.0	10.5	9.6	9.6
Bullock cart	5.5	5.7	6.0	5.9	6.5	6.3
Bicycles	-	-	-	-	-	-
Combined	37.3	35.2	34.9	33.9	33.7	33.4

Table 3.19 Comparison of Speeds of Vehicles on Intermediate Lane Plane Terrain for Different Power Weight Ratios

	200 veh/hr		300 veh/hr		400 veh/hr	
Vehicle Type	**Case 1**	**Case 2**	**Case 1**	**Case 2**	**Case 1**	**Case 2**
Ambassador	49.9	50.7	47.6	45.9	43.1	41.4
Fiat	53.4	55.4	51.5	50.6	44.1	42.1
Maruti	56.6	56.3	52.7	47.7	47.4	47.9
Jeep	51.5	51.8	47.6	46.1	40.7	41.9
Scooter	43.9	44.3	38.8	36.8	36.1	35.8
Matador Van	45.7	46.2	41.5	43.8	39.9	41.6
Bus	35.8	36.4	33.8	33.7	34.0	33.8
LCV	45.5	45.5	41.8	38.8	37.4	32.8
Truck	33.0	33.1	31.3	31.3	30.7	28.8
Tractor	20.5	20.4	19.2	20.3	18.5	19.4
Tempo	-	-	-	-	-	-
Horse cart	9.2	9.2	9.5	9.3	9.3	9.4
Bullock cart	5.7	5.6	5.9	5.7	6.1	6.0
Bicycles	-	-	-	-	-	-
Combined	43.7	44.0	39.5	38.1	35.1	35.0

Table 3.21 Comparison of Speeds of Vehicles on Single Lane Plane Terrain for Different Track 3 Speed Reduction Factors

	200 veh/hr		300 veh/hr		400 veh/hr	
Vehicle Type	**Case 1**	**Case 2**	**Case 1**	**Case 2**	**Case 1**	**Case 2**
Ambassador	33.3	33.1	32.5	33.0	33.3	32.7
Fiat	43.3	41.3	40.7	42.2	38.2	40.9
Maruti	36.7	36.9	36.0	36.1	35.3	35.3
Jeep	44.3	44.1	43.2	43.0	42.4	42.9
Scooter	38.4	38.3	36.2	37.3	33.9	37.3
Matador Van	37.1	36.9	33.9	36.2	34.5	35.7
Bus	27.6	27.0	27.3	26.5	27.2	26.3
LCV	35.7	35.2	33.9	33.4	35.6	34.9
Truck	30.3	29.5	30.0	28.4	29.4	29.1
Tractor	18.9	18.0	18.9	17.0	18.3	16.5
Tempo	-	-	-	-	-	-
Horse cart	9.4	9.1	9.9	9.0	9.6	9.2
Bullock cart	5.6	5.5	5.9	5.8	6.4	6.2
Bicycles	-	-	-	-	-	-
Combined	35.3	34.8	34.9	34.9	33.5	34.2

Table 3.22 Comparison of Speeds of Vehicles on Intermediate Lane Plane Terrain for Different Track 3 Speed Reduction Factors

	200 veh/hr		300 veh/hr		400 veh/hr	
Vehicle Type	**Case 1**	**Case 2**	**Case 1**	**Case 2**	**Case 1**	**Case 2**
Ambassador	50.7	50.6	45.1	48.5	42.1	46.7
Fiat	56.2	56.0	52.4	54.1	45.0	52.2
Maruti	56.7	55.8	52.5	54.1	48.7	52.7
Jeep	52.0	51.9	47.1	49.1	42.3	47.0
Scooter	44.1	43.7	41.5	40.9	36.7	39.4
Matador Van	46.2	45.4	41.9	44.2	40.3	42.9
Bus	36.1	35.4	34.7	33.6	34.9	33.6
LCV	45.6	45.0	42.1	44.3	36.8	40.1
Truck	32.9	32.5	30.7	30.6	30.6	30.9
Tractor	20.4	18.7	19.8	18.7	19.1	18.4
Tempo	-	-	-	-	-	-
Horse cart	9.1	9.0	9.6	8.8	9.4	8.8
Bullock cart	5.7	5.6	5.8	5.6	6.1	5.8
Bicycles	-	-	-	-	-	-
Combined	44.1	43.6	39.8	40.7	35.8	38.6

Table 3.24 Comparision of Speeds of Vehicles on Single Lane Plane Terrain for Different Basic Desired Speeds

	100 veh/hr		200 veh/hr	
Vehicle Type	**Case 1**	**Case 2**	**Case 1**	**Case 2**
Ambassador	33.9	34.5	32.6	33.0
Fiat	-	-	-	-
Maruti	36.9	37.6	36.1	32.3
Jeep	43.7	42.9	43.5	39.4
Scooter	38.0	36.5	36.5	34.5
Matador Van	-	-	-	-
Bus	27.9	28.0	27.4	26.1
LCV	37.6	37.4	36.6	35.1
Truck	30.1	30.1	29.6	28.5
Tractor	19.0	19.0	18.6	18.9
Tempo	-	-	-	-
Horse cart	9.4	9.1	9.3	9.3
Bullock cart	Inss	Inss	5.5	5.5
Bicycles	Inss	Inss	Inss	Inss
Combined	32.7	32.4	32.3	32.2

Table 3.25 Comparision of Speeds of Vehicles on Intermediate Lane Plane Terrain for Different Basic Desired Speeds

	100 veh/hr		200 veh/hr	
Vehicle Type	**Case 1**	**Case 2**	**Case 1**	**Case 2**
Ambassador	51.0	51.5	50.4	51.0
Fiat	-	-	-	-
Maruti	58.8	58.7	57.4	55.8
Jeep	52.1	51.8	51.2	50.8
Scooter	44.8	44.8	43.6	43.1
Matador Van	44.9	44.9	45.1	44.8
Bus	36.8	36.8	36.7	36.7
LCV	46.6	46.7	46.4	46.3
Truck	32.9	32.9	32.8	32.8
Tractor	-	-	-	-
Tempo	-	-	-	-
Horse cart	9.1	9.1	9.3	9.3
Bullock cart	Inss	Inss	5.4	5.4
Bicycles	Inss	Inss	Inss	Inss
Combined	45.6	45.7	46.1	46.3

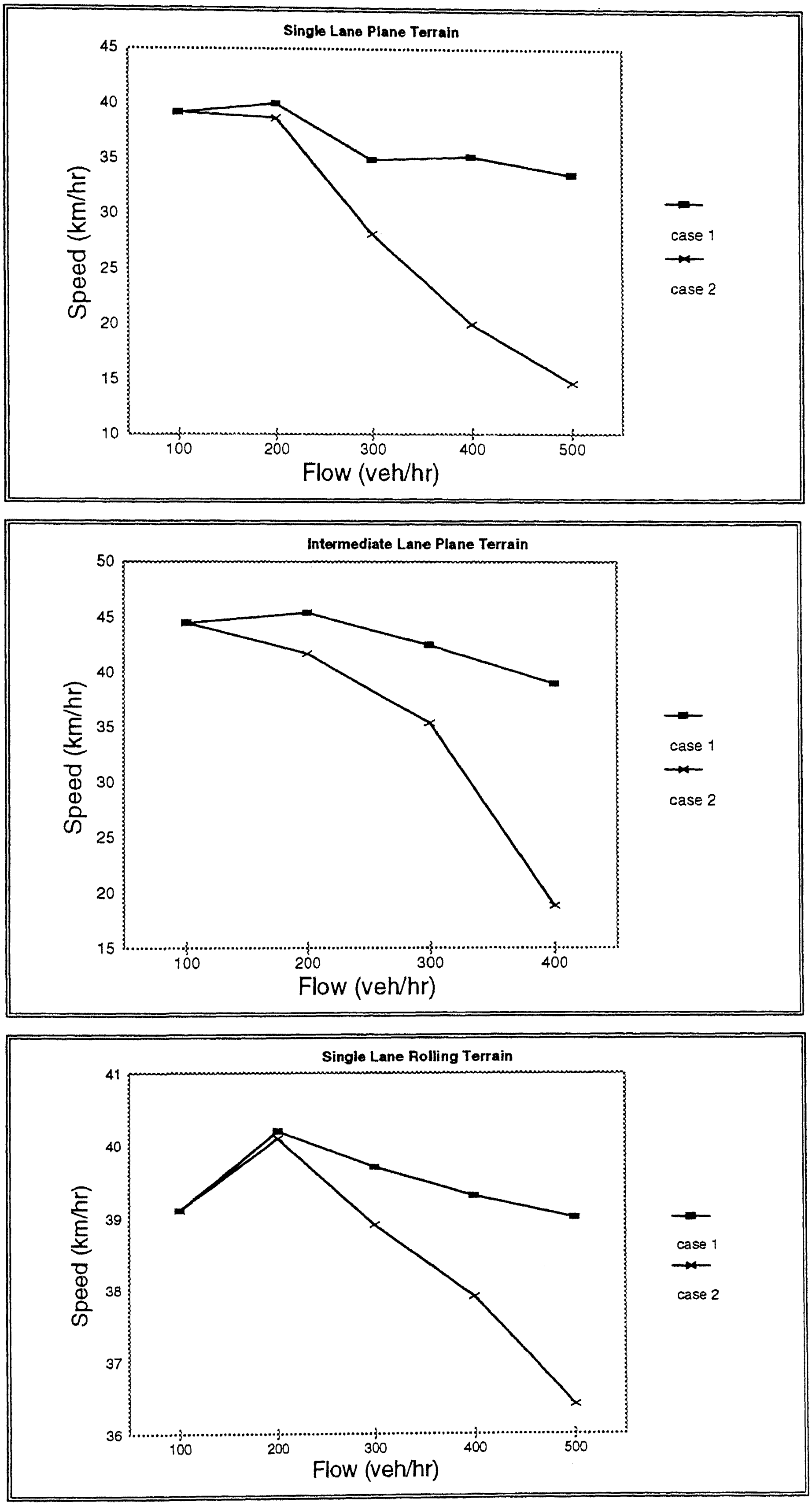
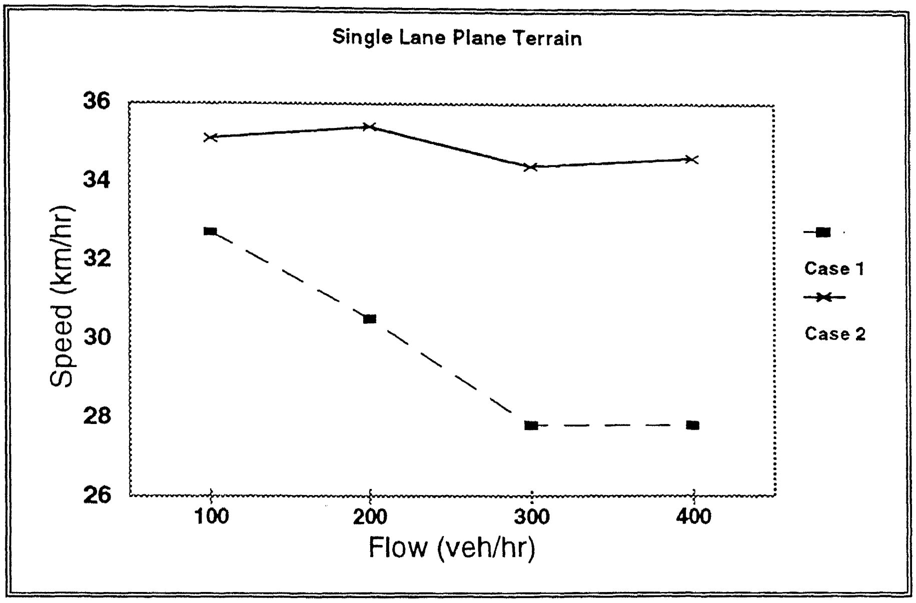


Fig 3.1-3.3 Sensitivity of Speed to Lane 3 Probabilities



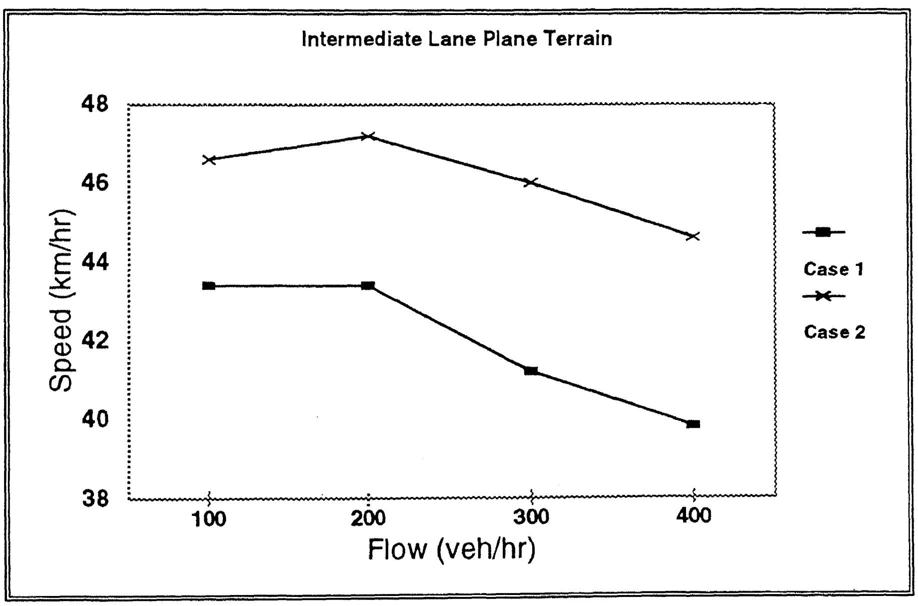
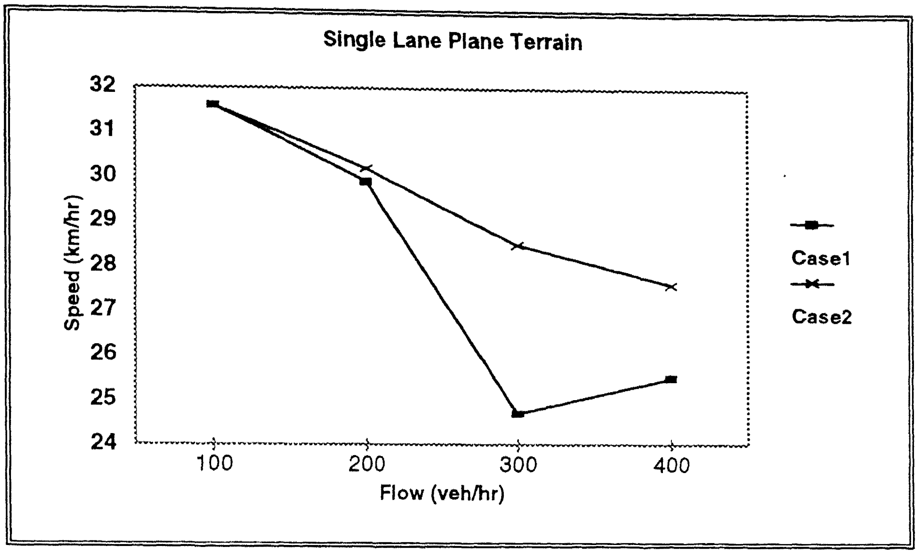
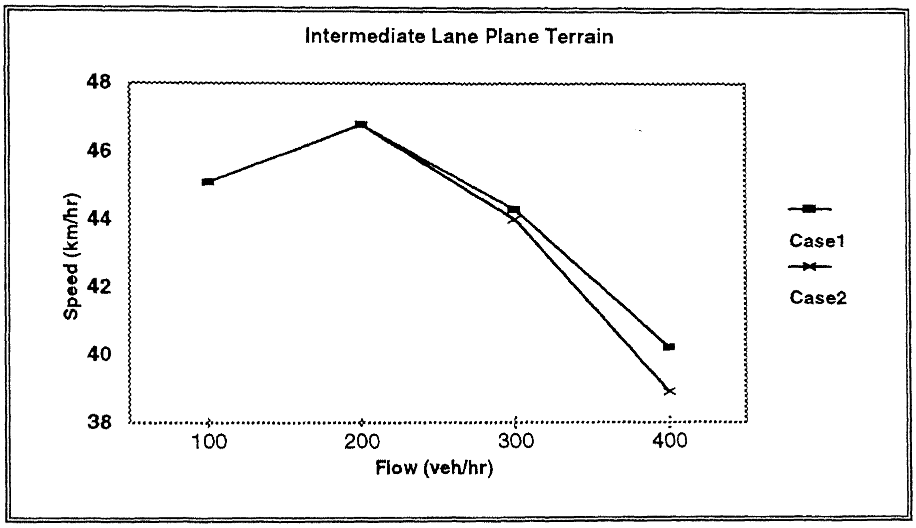


Fig 3.4-3.5 Sensitivity of Speed due to the Impedance of Slow Moving Vehicles





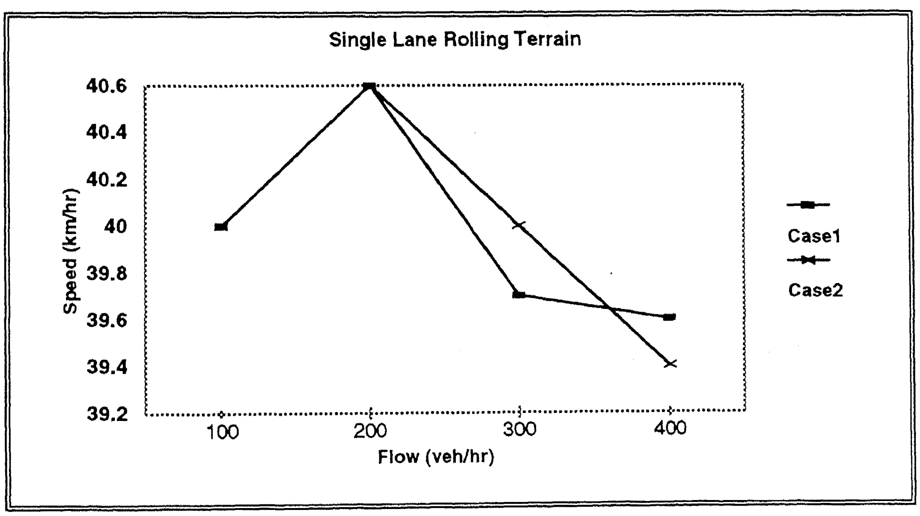
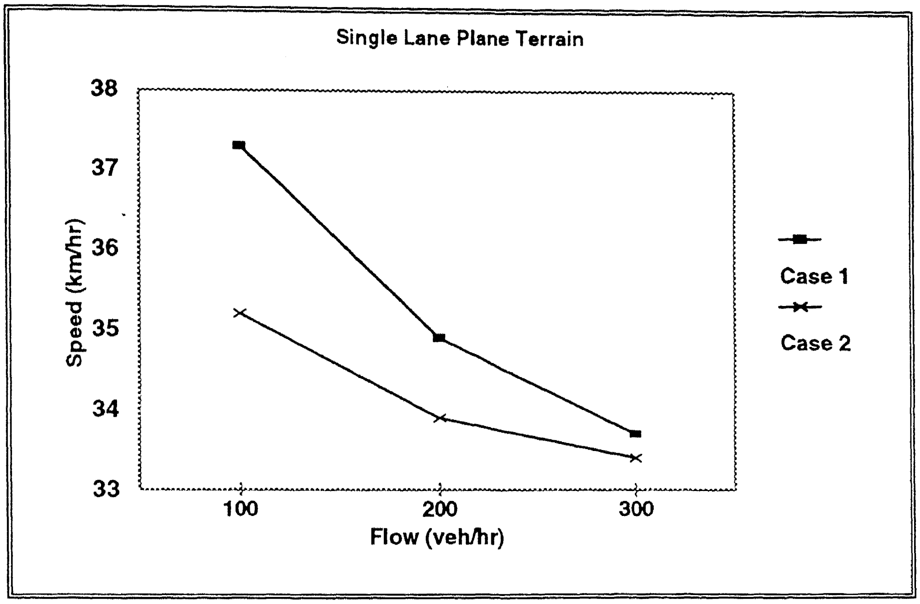


Fig 3.6-3.8 Sensitivity of Speed to Deceleration Rate



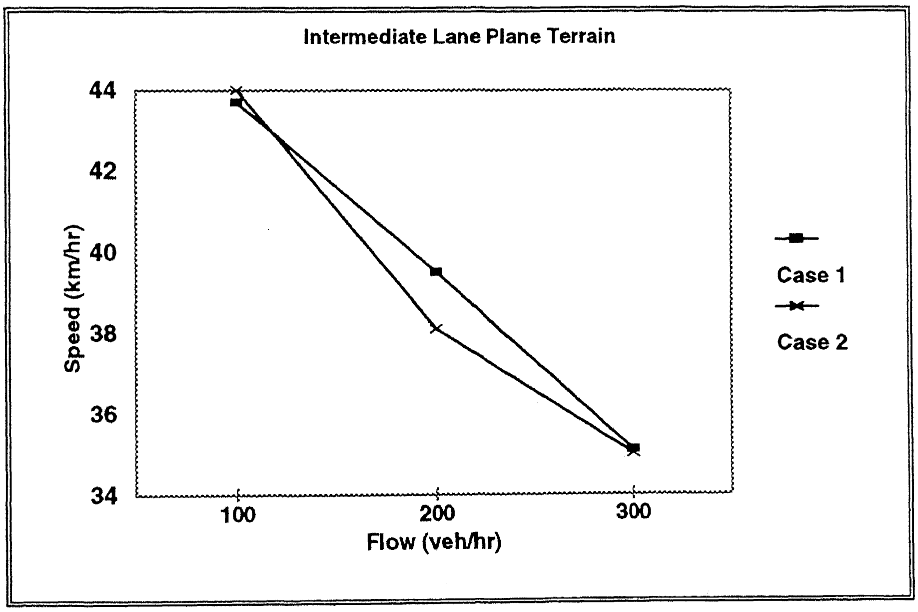
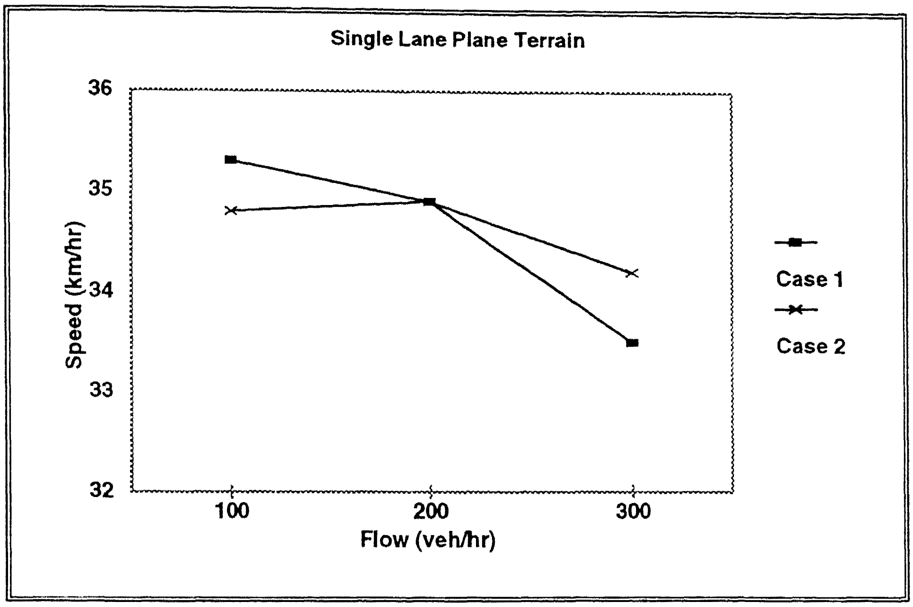


Fig 3.9-3.10 Sensitivity of Speed to Power weight Ratio



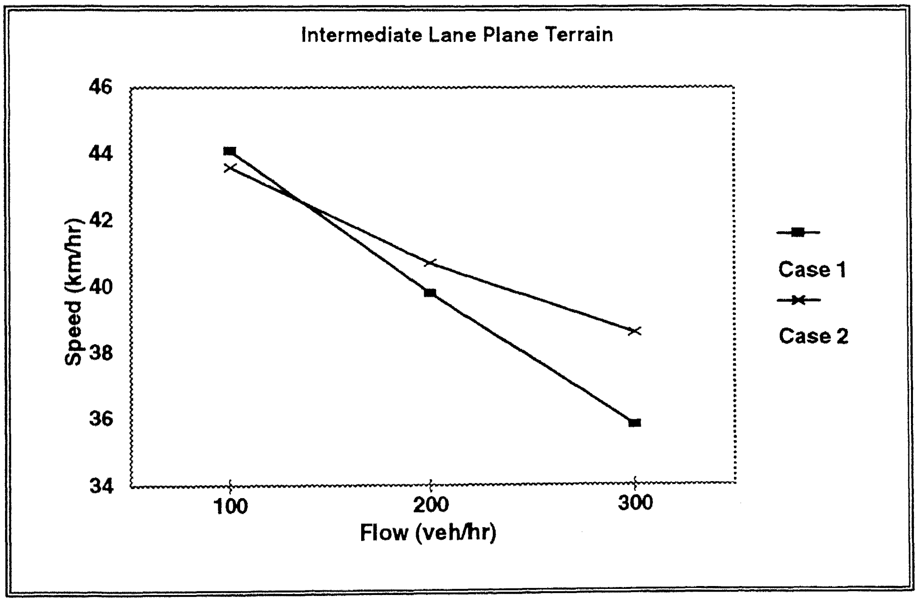
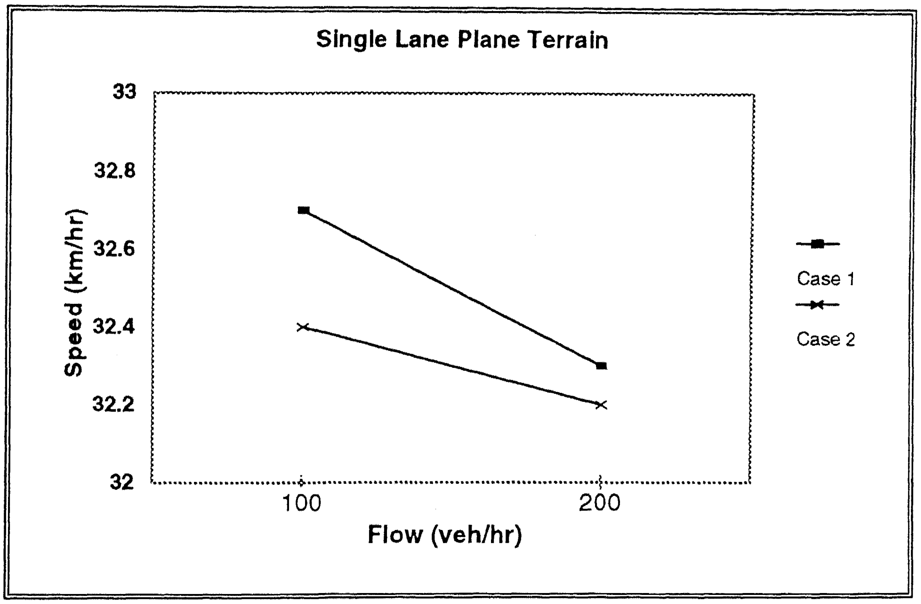


Fig 3.11-3.12 Sensitivity of Speed to Track 3 Speed Reduction Factor



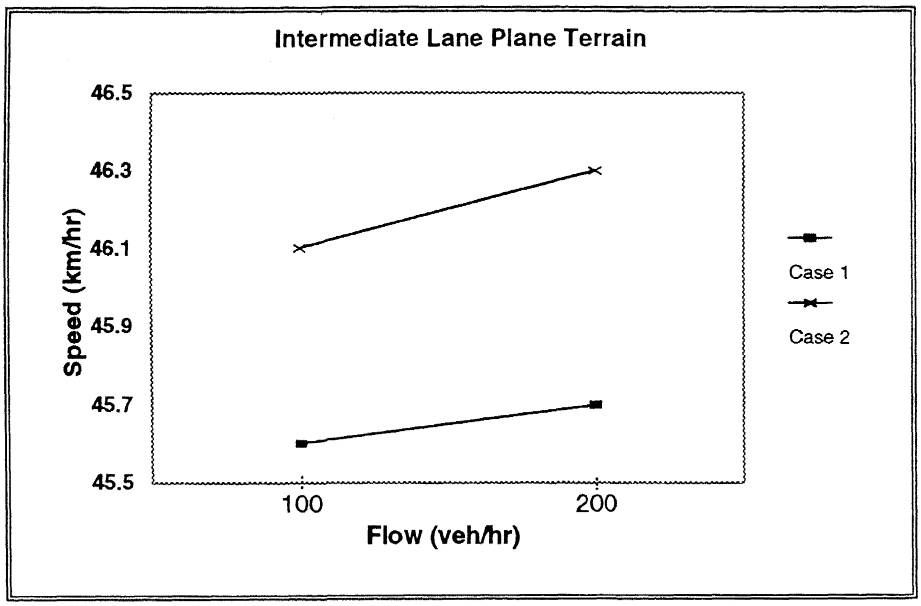


Fig 3.13-3.14 Sensitivity of Speed to Basic Desired Speed

CHAPTER 4

Analysis of Passenger Car Equivalents

4.1 Introduction

The heterogeneity of traffic on Indian roads makes it difficult to find analytical relationships between speed and flow. It is generally observed that the road space on Indian roads is utilized by the slow and fast moving vehicles at the same time. Also, the traffic interactions are more complex to observe and study, as no segregation of traffic is prescribed or followed on most of the Indian roads.

Different types of vehicles have their own characteristics such as speed, dimensions, flow logic, power to weight ratio and response to the presence of other vehicles. In addition the traffic composition varies from one place to the other (like urban and rural) and no one vehicle can really be considered as the predominant class for the entire country at present. We can take solace in the fact that the Maruti vehicle (Car, Van etc.) is fast dominating the scene in most of the urban and to some extent rural areas. Keeping this in view, Maruti Car is taken as the standard vehicle for all computational and comparison purposes in the present work.

The crux of the problem thus lies in developing speed-flow relationship involving such complex mix of vehicle types. From the above discussion it is also clear that, while developing speed-flow relationships we cannot simply add the numbers of different vehicle types to give the flow. A method has to be devised to present the actual effect of the heterogeneous traffic on the speed and behavior of different class of vehicles in the stream.

If we can convert vehicles of different types into a standard vehicle based on some criteria, the problem is solved. Usually the standard vehicle is taken as a passenger car and the conversion factor, which converts all vehicles into equivalent number of passenger cars, is called the PCE (Passenger Car Equivalent).

4.2 Definition of PCE

As explained in the previous section, the basic idea behind the concept of PCE is to determine the relative effect of different types of vehicles on the traffic flow as compared to a standard vehicle.

Though this idea seems to be fairly simple, the exact definition of PCE is not. In fact many definitions are possible and are practiced by different authorities. Some of the definitions are discussed below.

4.2.1 Definition in Terms of Speed

A common definition is the one adopted in U.K and is as follows:

If the addition of one vehicle per hour in the traffic stream reduces the average speed of the remaining vehicles by the same amount as the addition of, say, X cars per hour, then one vehicle of that type is considered equivalent to X PCE's.

The above definition emphasizes that the relative hindrance of any vehicle other than a car is to be taken in terms of its effect on speed alone.

4.2.2 Definition in Relation to Capacity

The 1965 HCM follows a definition which is related to the capacity of a road. In the words of HCM:

"Trucks reduce the capacity of a Highway in terms of total vehicles carried per hour. In effect each truck displaces several passenger cars in the flow. The number of passenger cars that each dual-tyred vehicle represents under specific conditions is termed as passenger car equivalent for these conditions".

This definition is more general and paves the way for calculating the PCE by different methods, which may lead to different results.

4.3 Earlier Work Done in India

In India very little work has been done on this front. In fact until RUCS has been carried out practically no work has been done even for developing speed-flow relationships on Indian highways.

PCE values are calculated for different types of Highways (Single as well as Multi lane) and for different type of terrains. The PCE values as suggested by RUCS are given in Table 4.1.

Although RUCS has been updated recently no attempt has been made to recalibrate PCE values; But IRC has revised PCE values from what they are suggested in RUCS, in its recent guidelines for capacity of roads in urban an rural areas([4] and [5]). These guidelines didn't mention as how these values are arrived at. The guidelines for capacity analysis on urban roads although acknowledge the fact that the PCE value of a vehicle is dependent on its percentage composition in the traffic, only two different compositions of a vehicle (less than or equal to 5% and greater than 10 %) are taken into account. The PCE values as recommended by IRC guidelines are given in Tables 4.2 and 4.3.

Table 4.1 PCE Values as Suggested in RUCS [10]

S.No.	Vehicle Type	PCE Value
1	Car	1.00
2	Bus	3.00 in Plane Terrain 4.00 in Hilly Terrain
3	Truck	3.00 in Plane Terrain 4.00 in Hilly Terrain
4	Tempo/Auto	4.00 in Plane Terrain 5.00 in Hilly Terrain
5	Tractor Trailer	4.00 in Plane Terrain 5.00 in Hilly Terrain
6	2-Wheelers	0.75
7	Bicycle	0.25
8	Cycle Rickshaw	1.00
9	Bullock Cart	6.00
10	Horse Cart	4.00

Table 4.2 Recommended PCE Factors for Various Types of Vehicles on Urban Roads[5]

S.No.	Vehicle Type	PCE Factor % Composition of Vehicle Type in Traffic Stream	
		< 5 %	10 % and Above
1	Motor Cycle or Scooter	0.50	0.75
2	Passenger Car: Pickup Van	1.00	1.00
3	Agricultural Tractor, Light Commercial Vehicle	1.20	2.00
4	Auto Rickshaw	1.40	2.00
5	Light Commercial Vehicle	2.20	3.70
6	Truck or Bus	4.00	5.00
7	Bicycle	0.40	0.50
8	Cycle Rickshaw	1.50	2.00
9	Horse Cart	1.50	2.00
10	Hand Cart	2.00	3.00

Table 4.3 Recommended PCE Factors for Various Types of Vehicles on Rural Roads[4]

S.No.	Vehicle Type	PCE Factor
1	Motor Cycle or Scooter	0.50
2	Passenger Car: Pickup Van	1.00
3	Agricultural Tractor: Light Commercial Vehicle	1.50
4	Truck or Bus	3.00
5	Truck-Trailer, Agricultural Tractor-trailer	4.50
6	Bicycle	0.50
7	Cycle Rickshaw	2.00
8	Hand Cart	3.00
9	Horse Drawn Cart	4.00
10	Bullock Cart	8.00

4.4 The Concept of Vehicle Throughput

Simply stated the throughput of a stream of traffic represents the number of vehicle kilometers of distance traveled by the stream in a unit interval of time.

Let's say that vehicles of vehicle type i pass a section of length S with an average speed V_i in a unit interval of time. Then the throughput of this stream can be written as

$$\text{Throughput} = X_i V_i \qquad ....(4.1)$$

Generalizing for a mixed traffic with vehicle types (i = 1..N) the throughput is given as

$$\text{Throughput} = \sum_{i=1}^{N} X_i V_i \qquad ...(4.2)$$

4.5 Computation of PCE Values Using Equivalent Vehicle Throughput Concept

Let's consider an all Maruti Car stream at a particular flow level, say F. According to the definition given in section 4.4, this stream will be having a particular throughput say 'X' veh-km/hr. If trucks are introduced into this stream at, say, P percent of the original flow, F, then throughput of the stream will reduce to 'Y' veh-km/hr. This reduction in throughput is due to the addition of trucks. It should also be noted that the throughput 'Y' consists of two components, the throughput of Maruti Cars (Y_M) and the throughput of Trucks (Y_T). Using the concept of equivalent vehicle throughput the PCE of truck (or any other vehicle) at the flow F and at P percentage composition of trucks can be computed as follows.

$$X = Y_M + Y_T * \text{PCE of truck} \quad .....(4.2)$$

$$=> \text{PCE of truck} = (X\text{-}Y_M/Y_T)$$

Since throughput at any flow level is calculated using the number of vehicles passed and the average speed of them, this method implicitly takes into account the speed differential among vehicles and also the number of vehicles actually passed at any particular instant.

PCE values have been calculated for truck using this method and the results are shown in Table 4.5. The results are plotted with flow as abscissa and PCE of vehicle as ordinate. The graphs are shown in Figure 4.3. To show how PCE of a vehicle is varying with

increase in percentage of truck, graphs are plotted with percentage truck as abscissa and the PCE of the vehicle as ordinate as shown in Figure 4.4.

The results show that the PCE of truck increases with flow level in a non linear manner. The PCE values are in a narrow range upto a flow rate of 400 veh/hr for all the composition of trucks. Beyond 400 veh/hr PCE values increases rapidly with the increase of flow. Again the increase is more pronounced at lower composition of trucks as can been observed from Figure 4.3 and 4.4. This reinforces the point discussed under section 4.8 that addition of trucks to the traffic streams is effective only to an extent beyond which there is no significant effect.

4.6 Computation of PCE Values Using Simulation Model

The single lane plane terrain road stretch between Unnaoh and Hardoi was considered for the study for which the model is calibrated. A road file has been prepared which corresponds to the conditions tabulated in Table 4.4 below.

Table 4.4 Road Attributes of Unnao to Hardoi Single Lane Plane Terrain Road.

Length (km)	Road Width (m)	Mean Rise (m/km)	Mean Fall (m/km)	Mean Roughness (mm/km)	Minimum Radius (m)	Maximum Radius (m)
3.020	4.0	15.895	12.915	5566	825	2292

At each flow level traffic has been generated first with Maruti-Cars in both directions. Maruties are then replaced by the Truck whose PCE value is to be computed, in steps of 20% varying from 20 to 80% and the traffic is again generated. After each traffic file has been generated, the main simulation has been run to produce the event file, which is then given as input to the results processing program which gives apart from other things the average speed of each vehicle and the number of vehicles of each vehicle type which have passed the section under consideration in the time interval selected. The throughput of the stream can be calculated using Eq 4.1 . The PCE of the vehicle can be computed using Eq. 4.2

The flow is now incremented and the above process is repeated to get the PCE value of a vehicle at different flow levels. The variation of throughput with flow is shown in Figures 4.1 and 4.2. The PCE Values are listed in Table 4.5 and plotted in Figures 4.3 and 4.4.

4.7 General Discussion on Results of PCE Values

The Results of PCE values reinforce the notion that PCE values of a vehicle differ with composition, flow , etc., and that a single PCE value should not be used for the purpose of capacity analysis. As shown in Tables 4.1 to 4.3, the peasant standards prevailing in India doesn't take this into account. The values suggested by RUCS and other IRC guidelines do not mention as to what composition and flow these values correspond to. For this reason the present PCE values cannot be compared with any of the above values. One reason why the researchers and planners couldn't consider this aspect is the absence of the huge amount of data, that is required for generating a PCE matrix. But the present work reinforces the advantages of simulation technique which has the potential information to offer in these types of situations.

Table 4.5 PCE Values of Trucks Using the Method of Equivalent Vehicle Throughput Concept

Flow (veh/hr)	Percentage of Trucks in Maruti-Truck Stream			
	20	40	60	80
100	1.25	1.25	1.25	1.25
200	1.26	1.24	1.25	1.25
400	1.32	1.31	1.28	1.27
600	1.61	1.48	1.38	1.32
800	1.73	1.66	1.42	1.33
1000	1.78	1.70	1.53	1.43

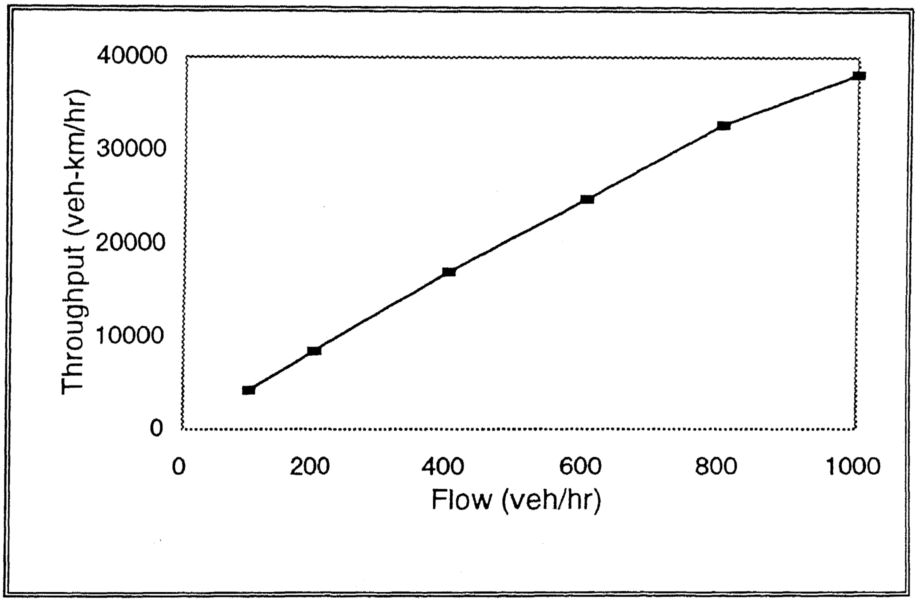


Fig 4.1 Variation of Throughput with Flow for Maruti Car Stream

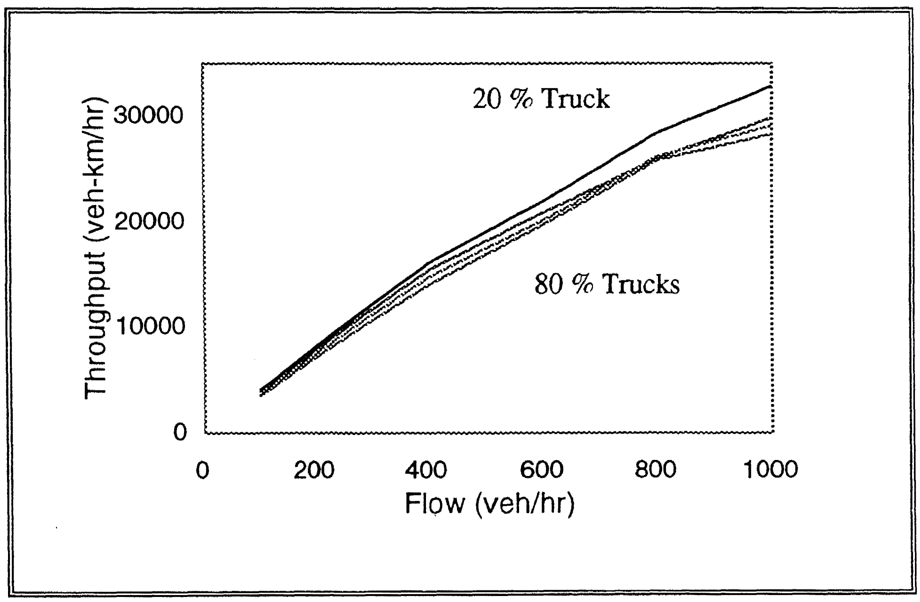


Fig 4.2 Variation of Throughput with Flow for Different Compositions of Trucks in Maruti Car Stream

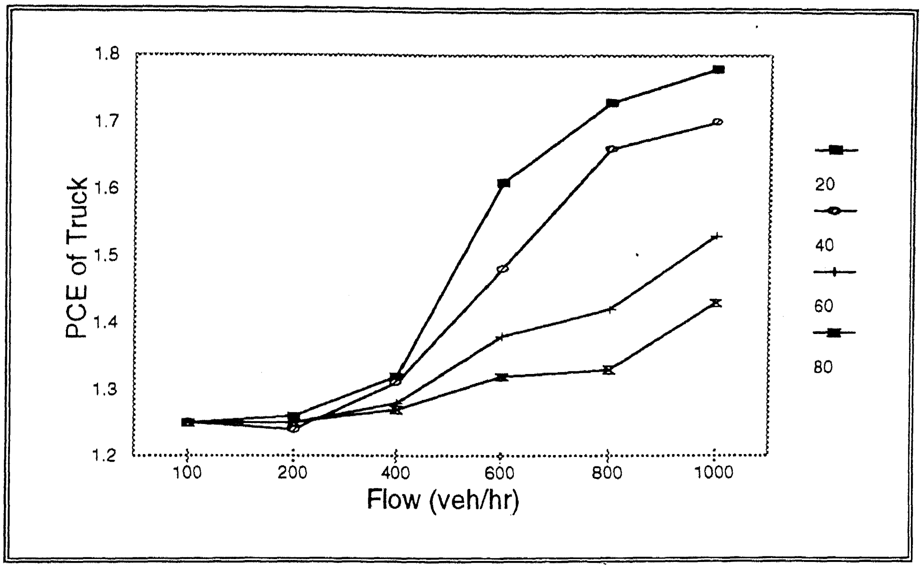


Fig 4.3 PCE Values of Truck at Different Flow Levels for Different Composition of Trucks

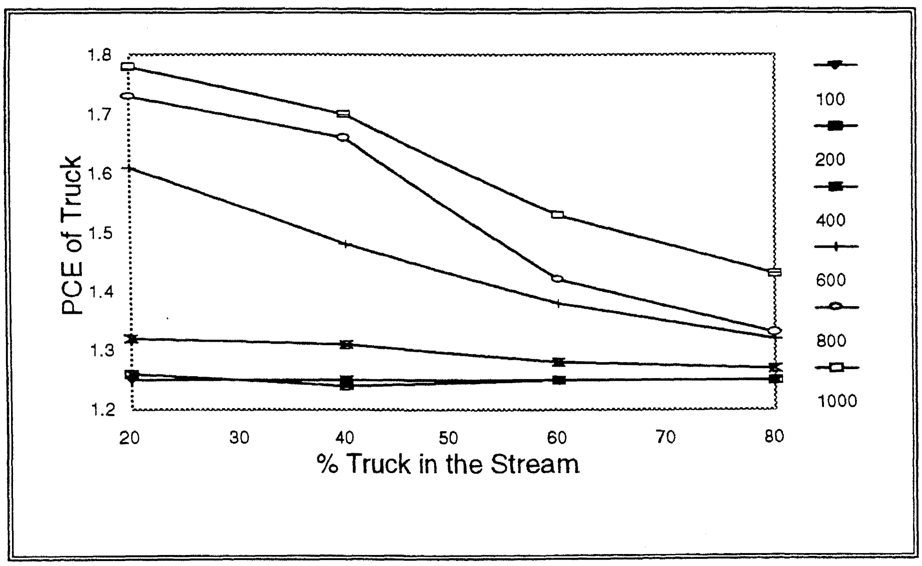


Fig 4.4 PCE Values of Truck at Different Compositions in the Stream for Different Flow Levels

4.8 Study of Acceleration Noise

Taylor, Miller and Ogden [14], suggest, based on the simulation techniques that the proportion of trucks in the flow does not significantly affect speeds for gradients below 3 percent. They also suggest an upper limit for the proportion trucks in the traffic stream above which the effect of an increasing proportion of trucks is not as great. This critical proportion was found to lie between 5 and 8%, the higher value corresponding to higher gradients. However, since speed alone does not represent the effect of trucks on the traffic stream and also to study the upper limit above which the addition of trucks in not as great, it was decided that the parameter, acceleration noise (see below for definition) which essentially indicates the jerkiness/smoothness [3] of the flow be studied to get a clear picture of the variations in the traffic stream as the proportion of truck increases.

The acceleration noise is mainly influenced by the three factors, road, driver and traffic condition. A narrow highway with substandard curves and grades will force the drivers to accelerate and decelerate more frequently and the value of acceleration noise of such road will be greater than for a well-designed expressway. An aggressive driver will have a large acceleration noise than the steady driver. Traffic congestion, produced by the increased traffic demand or road side activity, will also increase the acceleration noise.

4.8.1 Definition of Acceleration Noise and Methodology of Computation

The acceleration noise (broadly defined as the standard deviation of accelerations of a vehicle) can be considered as the disturbance of vehicle's speed from a uniform speed, or can be identified as a measurement of the smoothness of traffic flow.

Since the simulation model gives the speed profile of any vehicle, acceleration noise can be easily computed using the following equation given by Drew [3]

$$\sigma = \frac{(\Delta v)^2}{T} \sum_{i=0}^{T} (n^2/\Delta t_i)$$

where

σ = Acceleration Noise of a vehicle in m/s^2

Δv = Change in velocity of interest

T = Total journey time in seconds

n = Number of changes of Δv in time Δt_i

4.8.2 Results and Interpretation of Variation of Acceleration Noise

Table 4.6 gives the variation of acceleration noise of truck at different flow levels and at different percent composition of these vehicles in the base stream. These results are plotted with percent composition of the vehicle as abscissa and acceleration noise as the ordinate.

The following conclusions can be drawn from the Figs 4.5 and 4.6.

1. The peak of the acceleration noise curve shifts from right to left as the flow varies, indicating that the effect of adding truck, prevails for longer duration (in terms of percentage of truck) when the flow levels are less compared to higher flow levels.

2. The upper limit for the addition of trucks, above which more addition of them results in decrease in acceleration noise, depends heavily on the flow rate. For example for trucks this percentage varies from 40% at 600 veh/hr flow to 20% at other flow rates.

3. There is no significant increase in acceleration noise of the stream when 20 % trucks are added to the Maruti Stream. This reinforces the points discussed in section 4.8 that critical proportion of trucks is some where between 5 to 8% beyond which addition of them does not contribute to the increase in acceleration noise.

Table 4.6 Acceleration Noise (m/s^2) of Maruti-Truck Stream

% Truck	Flow (Veh/hr)					
	100	**200**	**400**	**600**	**800**	**1000**
0	0.075	0.086	0.094	0.085	0.080	0.091
20	0.076	0.080	0.094	0.085	0.080	0.091
40	0.071	0.065	0.075	0.066	0.084	0.078
60	0.055	0.059	0.067	0.066	0.073	0.069
80	0.053	0.054	0.050	0.051	0.057	0.056

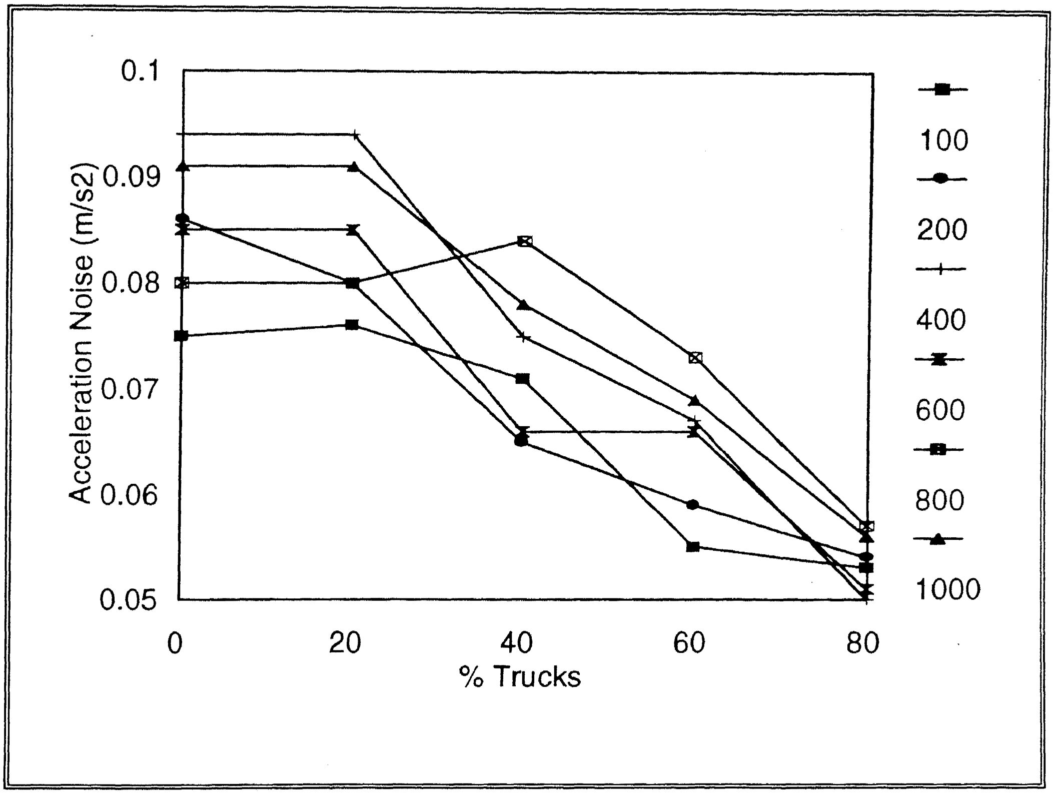


Fig 4.5 Acceleration Noise of Truck-Maruti Stream for Different Composition of Trucks at Different Flow Rates

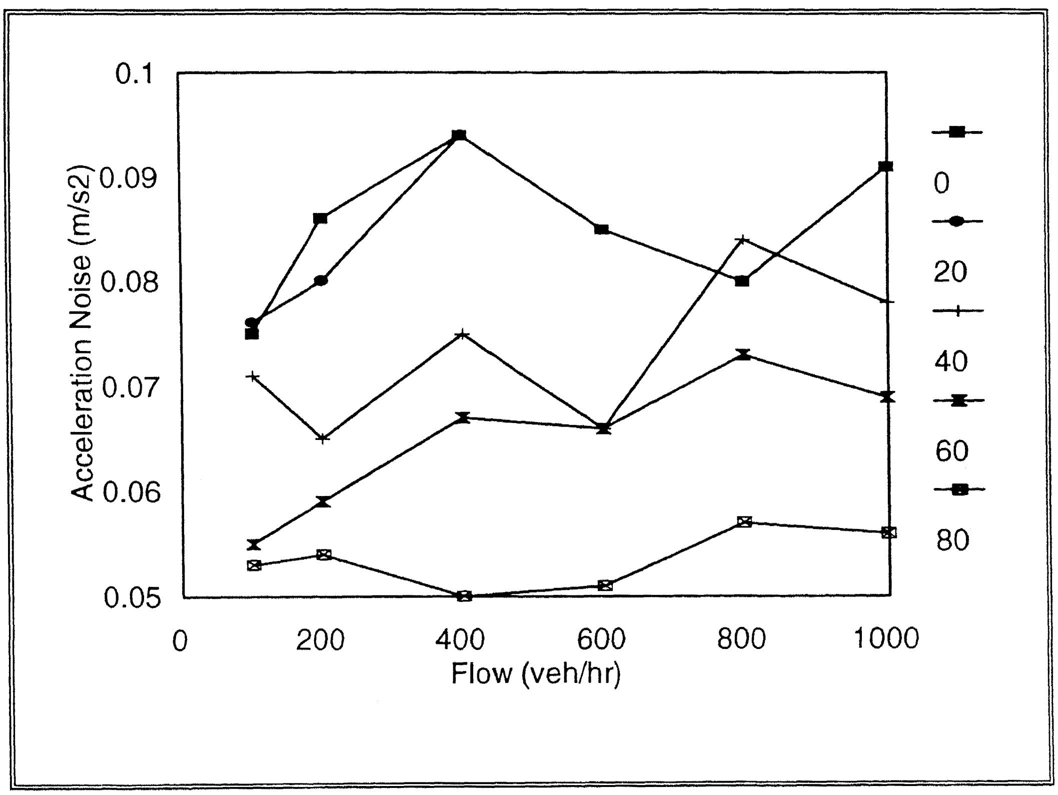


Fig 4.6 Acceleration Noise of Truck-Maruti Stream for Different Flows at Different Composition of Trucks

CHAPTER 5

Level of Service Analysis of a Single Lane Road

5.1 Introduction

A critical need in traffic analysis is a clear understanding of the ability of various types of facilities to carry traffic. This knowledge when integrated with measurements of current traffic and forecasts of future traffic demand, allows the traffic engineer to plan and design facilities that can adequately serve the society's needs.

Capacity analysis can be defined as the study of various types of highway facilities and their ability to carry traffic. Capacity analysis does not seek to identify merely the maximum amount of traffic that a facility can handle, but also the amount of traffic that can be accommodated at various defined levels of operational quality. Thus the capacity analysis is a part of every form of traffic analysis, including planning and design, operational analysis, analysis and evaluation of controls and analysis of alternatives.

5.1.1 The Level-of-Service Concept

The level-of-service is a letter designation that describes a range of operating conditions on a particular type of facility. The 1985 Highway Capacity Manual defines the level-of-service concept as "*a qualitative measure describing operational conditions within a traffic stream and their perception by motorists and/or passengers.*"

The above definition implies that the service quality should be described in terms that can be perceived by passengers. Several measures like speed, travel time, density and delay are used in the Highway Capacity Manual. In addition, parameters like acceleration noise, number of overtakings (passings), number of crossings per km, etc., which are not directly discernible to passengers, have also been used for defining level-of-service in this (research work) thesis.

Before 1980, practically very little research has been done on this important field. The Road User Cost Study, funded by the World Bank through Ministry of Surface Transport and implemented by the Central Road Research Institute, took upon itself the task of conducting speed-flow studies in different parts of the country and collecting a wealth of data on roads of different widths. The other areas covered by RUCS are

- Determination of PCE for different vehicle types and under different road conditions.
- Collection and analysis of vehicle operating cost data.
- Accident and fuel consumption study.
- Study of value of travel time savings.

Since 1980, vast changes have taken place in the transportation scenario in our country. The technology of vehicles itself has undergone major changes. The second important development that has taken place is the modernization of the road itself. Majority of the two lane highways are being converted into four lane highways.

Keeping in view these developments the Ministry of Surface Transport commissioned a study for updating road user costs in collaboration with the Asian Development Bank.

The important conclusions arrived at during the revision of RUCS, as regards speed-flow research component of it are

- The speeds of vehicles on two lane and four lane roads have increased by 10-40 percent. The increase is partly due to the improvements in vehicle technology and partly due to the improvement in road conditions.

- Speeds of vehicles have not changed on single and intermediate lanes during the last decade, the narrow road width dictating speeds.

- The drop in speed as the flow increases is much more pronounced now than in 1980.

- The capacity values as suggested in IRC guidelines need to reviewed.

The study is limited by the fact that it calculates capacities by taking PCE values from the IRC guidelines which are only tentative.

5.3 Present Work

It is customary in the capacity analysis to calibrate capacity of a facility for ideal traffic, roadway and control conditions. These are then modified to account for the prevailing conditions that are not ideal. Hence the present work focuses on the evaluation of capacity and description of level-of-service on a single lane road. The following sections describe the methodology, implementation and results of the analysis.

5.3.1 Selection of Measure of Effectiveness Parameters

As described in section 5.1.1 level-of-service is described in terms of quality terms that are perceived by the drivers and passengers. So, before defining level of service for any type of facility it is essential to choose quality terms that can be perceived and evaluated by passengers on that type of facility.

On narrow roads, drivers are often engaged in following a vehicle as the road width is insufficient to overtake. The following continues as long as the leading vehicle doesn't give way for the following vehicle to pass. Hence the amount of time a vehicle spends in following another vehicle, or the "average percentage of total travel time a vehicle spends in following," aptly described by Highway Capacity Manual as the "percent time delay" can be used as a measure of effectiveness parameter in describing the level of service.

Also, speeds on narrow roads are observed to be very less even during low flow levels. Also speed is a parameter that the driver in a traffic stream is usually aware and concerned with. The other advantage is that speed can be determined easily. Hence the speed can be used as a descriptor of the level of service.

The density of traffic stream describes the proximity of vehicles to each other in the traffic stream and reflects the ease of maneuverability in the traffic stream. So the density is another parameter which can be considered for the evaluation of level of service.

As it is difficult to obtain percent time delay using the present form of output of the simulation model, it was decided that speed and density of the traffic stream be used for defining level of service.

5.3.2 Methodology

For evaluating the capacity of a single lane road the following road and traffic characteristics is taken.

- Design Speed ≤ 50 Km/Hr
- 4.0 m width carriage way
- 2m width shoulders on either side
- Level terrain
- 50/50 directional distribution of traffic
- Only Maruti Cars in the traffic stream

The road attributes of this single lane plane terrain road are presented in Table 4.4. The capacity of the single lane road is arrived at by studying the speed–throughput relationships. It is to be noted that in the present study throughput is used instead of flow as the flow in this study will only represent the demand. For example if we send some flow the resulting throughput of the stream is the manifestation of this flow and hence a better representative of the flow. Capacity of a road section is defined as the flow (in PCE/hour) corresponding to the maximum throughput achievable. Level of service is determined using the speed and density as the main criteria. In a similar manner the change in the level of service due to change in the speed–throughput–density relationships with each increment of truck traffic is studied.

5.3.2.1 Computation of Density from Simulation Model Experiments

The density of a traffic stream is defined as the number of vehicles occupying a unit section of the road at any given time. Since it is difficult to locate every vehicle at a particular instant using the model the following method which uses the principle of conservation of vehicles is used.

Three traps namely A, B, C are selected on the road as shown in the Fig 5.1. Now the number of vehicles leaving each of the traps in a time interval say, 'x' seconds, are noted.

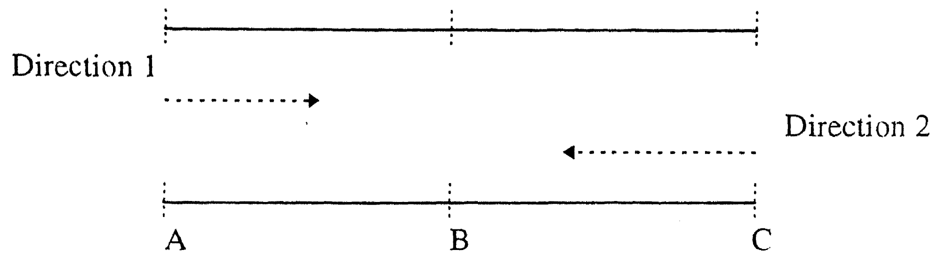


Fig 5.1 Bidirectional Single Lane Road

Let the number of vehicles leaving each trap in this same interval be N(A), N(B) and N(C) respectively, in direction 1. As what ever flow gets in has to get out, We can say that in the time interval 'x' seconds N(B)−N(A) vehicles are present in direction 1 in section A−B, N(B)−N(C) are present in direction 1 in section B−C. Similarly in the same time interval 'x' seconds N(C)' N(B)' N(A)' leave traps C, B, and A in direction 2. The density (or its surrogate measurement) can now be defined for trap A−B, B−C and for the whole section A−C (in the time interval x seconds) as follows.

$$\text{Density}_{A\text{-}B} = (N(A) - N(B)) + (N(B)' - N(C)')$$

$$\text{Density}_{B\text{-}C} = (N(B)-N(C)) + (N(C)'-N(B)')$$

$$\text{Density}_{A\text{-}C} = (N(A)-N(C)) + (N(C)'-N(A)')$$

The process is repeated for each time interval for a total of an hour in which a time period of 'y'(say, 5min) at the start and end of the simulation is not considered for the calculation of density. This ensures that the density calculated corresponds to flow at stable conditions. The time interval 'x' is selected on the basis of the average speed of the stream.

5.3.3 Implementation of the methodology using the Simulation Model

5.3.3.1 Speed–Throughput–Density Relationships for all Maruti Stream

A road file corresponding to the conditions mentioned in section 4.6 is prepared. This road file is used for all the computation purposes. For studying the capacity of Maruti Car stream the traffic is simulated where flow (or demand) is varied form 100 veh/hr (also equal to PCE/hour) to 1000 veh/hr (combined in both directions) and corresponding lane 3 probabilities given in Table 3.4 are used. At each flow level the average speed of the stream, the density and throughput of the stream are calculated using post processing programs. Table 5.1 shows the results obtained.

Graphs depicting the variation of speed–throughput and speed-density are shown in Fig 5.2 and Fig 5.3., respectively. The speed–throughput relationship shows a parabolic pattern with speed decreasing as throughput increases. The speed–density relation indicates a linear pattern with speed decreasing as the density increases.

The level of service has been calibrated using speed and density as the criteria. This is shown in Table 5.2.

Table 5.1 Speed–Throughput–Density Relationships of Maruti Car Stream

Demand (veh/hr)	Speed Statistics (km/hr)		Throughput (veh-km/hr)	Density (veh/km)	
	Mean	Std. Dev		Mean	Std. Dev
100	42.7	2.6	4227	1.00	0.35
200	42.5	2.5	8458	1.90	0.59
400	42.5	2.4	17000	3.92	1.21
600	41.3	2.0	24739	6.13	0.80
800	40.7	2.1	32682	7.66	1.72
1000	38.3	5.0	38185	11.26	4.39

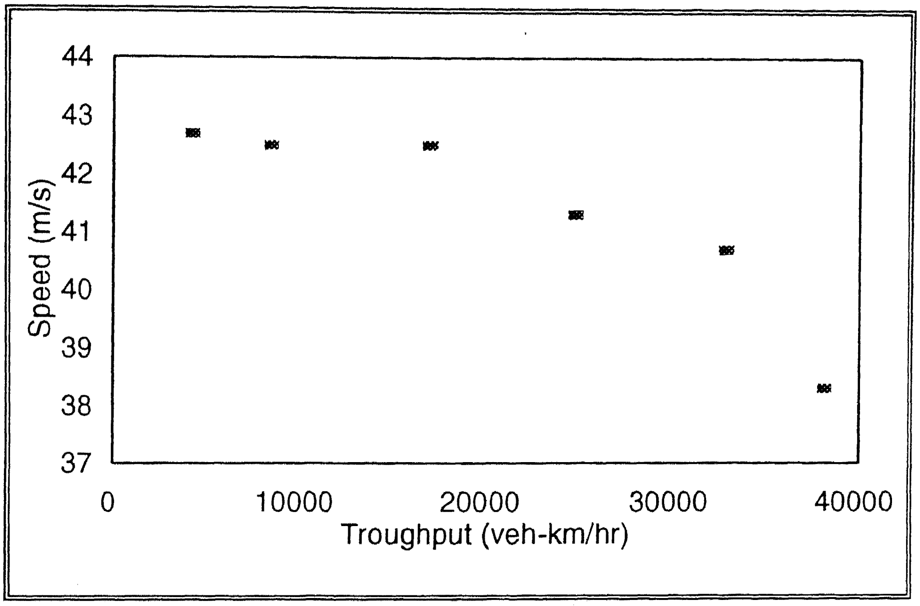


Fig 5.2a Speed-Throughput Variation of Maruti Car Stream

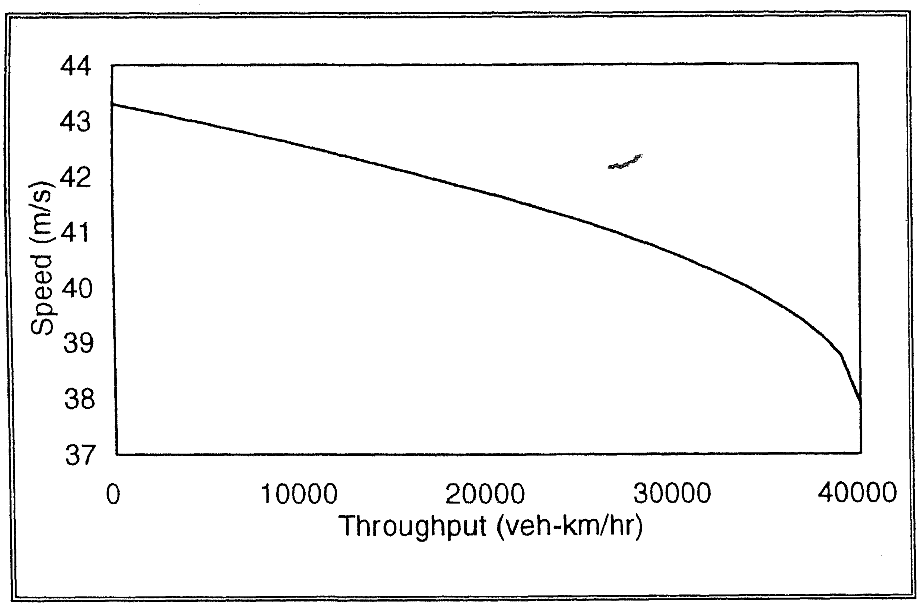


Fig 5.2b Approximated Asymmetric Parabolic Speed-Throughput Variation of Maruti Car Stream

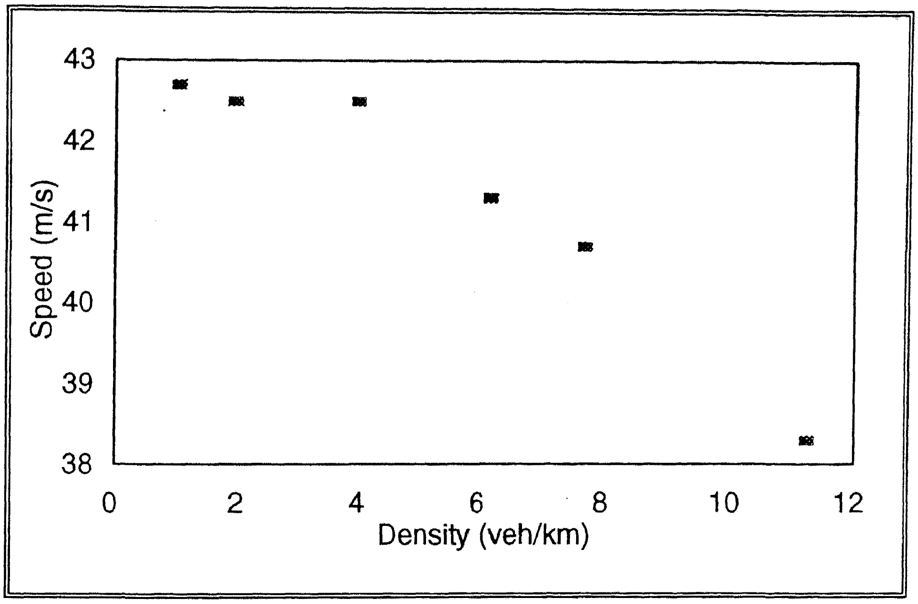


Fig 5.3 Speed-Density Variation of Maruti Car Stream

Table 5.2 Speed and Density Values at Various Operating Conditions for Maruti Car Stream

Level-of-service	Speed (Km/Hr)	Density (PCE/Km)
A	> 43.00	< 1.0
B	41.75 - 43.00	1.0 - 5.3
C	40.50 - 41.75	5.3 - 8.0
D	39.25 - 40.50	8.0 - 9.8
E	38.00 - 39.25	9.8 - 11.0
F	< 38.00	> 11.0

The effect on speed-throughput-density relationships of Maruti Car stream due to each incremental addition of truck is discussed in the following section.

5.3.3.2 Speed–Throughput–Density Relationships for Maruti–Truck Stream

For studying the above effect trucks are introduced in the Maruti Car stream by replacing Maruti Cars by trucks. The proportion of trucks replacing Maruti Cars is increased in steps of 20% until all the Maruti Cars are replaced by trucks. At each step the flow is varied from 100 veh/hr to 1000 veh/hr combined in both directions and lane 3 probabilities listed in Table 3.4 are used for simulating the traffic. For each flow level speed, throughput and density are noted. The results are presented from Table 5.3. to 5.6.

Table 5.3 Speed-throughput-Density Results for 20 % Trucks in Maruti-Truck Stream

Demand (veh/hr)	Speed Statistics (km/hr)		Throughput (veh-km/hr)	Density (veh/km)	
	Mean	Std. Dev		Mean	Std. Dev
100	40.9	4.2	4048	1.04	0.36
200	40.8	4.0	8126	1.98	0.62
400	40.1	3.8	16054	4.23	1.22
600	36.7	3.2	21997	6.63	1.09
800	35.6	3.0	28431	8.49	1.71
1000	32.8	4.1	32796	12.72	4.09

Table 5.4 Speed-throughput-Density Results for 40 % Trucks in Maruti-Truck Stream

Demand (veh/hr)	Speed Statistics (km/hr)		Throughput (veh-km/hr)	Density (veh/km)	
	Mean	Std. Dev		Mean	Std. Dev
100	38.9	4.6	3850	1.09	0.36
200	39.4	4.6	7846	2.03	0.63
400	38.3	4.1	15356	4.39	1.29
600	34.9	2.5	20941	6.88	1.19
800	32.5	3.5	26005	9.83	3.06
1000	29.8	4.6	29849	16.24	8.41

Table 5.5 Speed-throughput-Density Results for 60 % Trucks in Maruti-Truck Stream

Demand (veh/hr)	Speed Statistics (km/hr)		Throughput (veh-km/hr)	Density (veh/km)	
	Mean	Std. Dev		Mean	Std. Dev
100	37.4	4.4	3698	1.11	0.38
200	37.5	4.3	7471	2.10	0.65
400	36.7	3.9	14705	4.56	1.17
600	33.6	2.2	20199	7.22	1.22
800	32.7	2.6	26176	9.68	2.58
1000	31.9	2.5	29102	13.42	3.76

Table 5.6 Speed-throughput-Density Results for 80 % Trucks in Maruti-Truck Stream

Demand (veh/hr)	Speed Statistics (km/hr)		Throughput (veh-km/hr)	Density (veh/km)	
	Mean	Std. Dev		Mean	Std. Dev
100	35.5	3.5	3508	1.16	0.37
200	35.7	3.5	7116	2.24	0.66
400	35.0	3.0	13994	4.81	1.27
600	33.0	1.7	19779	7.18	1.71
800	32.3	2.2	25860	9.21	2.62
1000	28.5	4.1	28317	15.00	5.21

Graphs are plotted with speed as ordinate and throughput as abscissa for all the results. We know that the theoretical speed-flow curve follows a parabolic variation. But it need not be true always. The behaviour of the stream in the free flow codition and forced flow condition need not be the same. Keeping this in view, these curves are approximated by asymmetrical parabolas. For fitting these curves it is assumed that the parabola is uniquely determined by x, y and 'a'. The method of least squared errors is used for fitting parabolas. The characteristics of the curves are presented in Table 5.7. It can be observed from Fig 5.4 that the speed drop becomes more pronounced as the proportion of the truck increases, resulting in steeper curves.

Table 5.7 Characteristics of the Asymmetrical Parabola for Truck

% Truck in the stream	Characteristics of the curve		
	X	Y	a
0	40000	37.9	-0.00018
20	33000	33.5	-0.00020
40	30000	29.7	-0.00093
60	30000	31.5	-0.00032
80	30000	28.2	-0.00059

Note : The equation of the parabola is $(y-Y)^2 = -4a(X-x)$

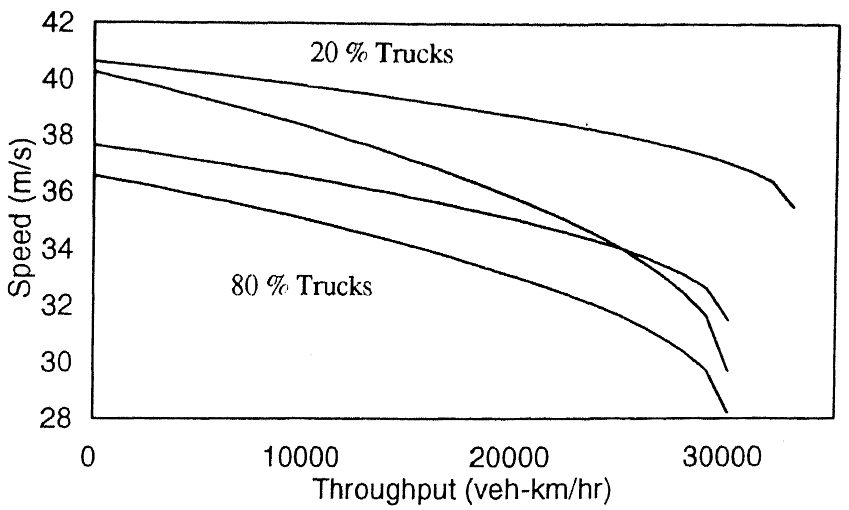


Fig 5.4 Approximated Asymmetric Parabolic Speed-Throughput Variation of Maruti Car Stream

The various possible levels-of-service conditions when truck is introduced into the Maruti Car stream are presented in Table 5.8. These conditions are arrived at by using speed as the sole criteria in accordance with the norms given in Table 5.2. It can be seen that the only level of service 'F' is available for the addition of trucks beyond 40% and that the highest level of service available is 'C' at 20 % trucks in the Maruti-Truck stream and at a flow rate less than 200 veh/hr.

Table 5.8 Various Available Levels of Service when Truck is Introduced in all Maruti Car Stream

% Trucks in the stream	Available Levels of Service on SingleLane
20	C, D, E, F
40	D, E, F
60	F
80	F

5.4 Study of Shoulder Usage

As stated earlier the Indian highway scene is mostly dominated by the narrow roads (i.e. single lane and intermediate lane roads). The shoulders on these roads play a useful role in traffic operations such as passing and crossing.

For a faster vehicle to pass a slower vehicle in front, it is necessary that the lead vehicle (slower) should yield by moving partly to the shoulder. If both the interacting vehicles are wider (i.e. bus or truck), the yielding vehicle will use the shoulder on one side and the passing vehicle will use the shoulder on the other side. In crossing manouver also both the vehicles have to move partly to the shoulder on either side to have a safe crossing.

Owing to such extensive use of shoulder on these roads it was felt necessary to study some of the parameters such as number of passings and average speed on shoulders which will be useful for traffic engineers and planners to decide on the type of shoulder to be used and maintenance strategy for the existing shoulders.

5.4.1 Speed of Vehicle on the Shoulder during Passing

In the model whenever the slower vehicle yields by moving to Track3 (i.e. shoulder) its speed on the shoulder is taken as

$$V3 = TRK3VRED * V2$$

where,

V3 - Speed on the Shoulder

V2 - Speed on the Carraigeway

TRK3VRED - Reduction Factor

It was assumed that whenever the vehicle have to use the shoulder in crossing or in passing manuover its speed will be the same in both the cases. The reduction of speed on the shoulder is related to its speed on the Carraigeway before encountering the passing and crossing manouver [11] . The reduction in speed will be more for faster vehicles and less for slower vehicles. It was assumed that TRK3VRED will follow the pattern as shown in Fig 5.5. In which "μ" is the minimum value of TRK3VRED when the speed of vehicle before crossing or passing manouver is free speed "v", and "v'" is the speed of vehicle below which the vehicle will not reduce it's speed while yielding to the shoulder .

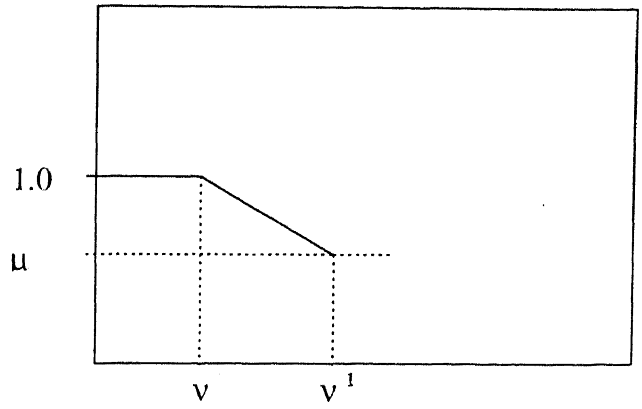


Fig 5.5 Varuation of TRAK3VRED

5.4.2 Use of Simulation Model

The simulation model keeps track of every change the vehicles encounters during their movement over the study stretch. The simulation model output cannot give directly the speed of vehicle on the shoulder. But knowing the space and time coordinate, each time when the shoulder was used by a vehicle, the speed of the vehicle on the shoulder was calculated. The total number of passings and the average speed on the shoulder at different flow levels for the Maruti Car stream is given in Table 5.9 and for different composition of truck in Maruti Car stream is given in Table 5.10a&b. The variation of the average speed on shoulder and the total number of passings at different flow levels for the Maruti Car stream is given in Fig 5.6. and Fig 5.7., and for different composition of truck in the Maruti Car stream is given in Fig 5.8a-b and Fig 5.9.

Table 5.9 Average Shoulder Speed and Number of Passings Relationships of Maruti car Stream

Flow (veh/hr)	Average Shoulder Speed (km/hr)	Number of Passings
100	38.09	11
200	37.41	47
400	37.13	88
600	-	0
800	-	0
1000	-	0

Table 5.10a Average Shoulder Speed of Maruthi in Maruti-Truck Stream

% Trucks in the stream	Flow (veh/hr)					
	100	200	400	600	800	1000
20	40.48	34.96	35.16	-	-	-
40	39.94	35.42	33.72	-	-	-
60	40.73	34.48	31.27	-	-	-
80	38.19	27.11	30.97	-	-	-

Table 5.10b Average Shoulder Speed of Truck in Maruti-Truck Stream

% Trucks in the Stream	Flow (veh/hr)					
	100	200	400	600	800	1000
20	33.00	32.59	32.92	-	-	-
40	33.26	32.29	31.65	-	-	-
60	32.78	31.25	30.13	-	-	-
80	31.78	31.73	31.49	-	-	-

Table 5.11 Number of Passings for Different composition of Trucks in Maruti-Truck Stream

% Trucks in the Stream	Flow (veh/hr)					
	100	200	400	600	800	1000
20	26	60	106	0	0	0
40	30	73	108	0	0	0
60	24	66	101	0	0	0
80	28	63	91	0	0	0

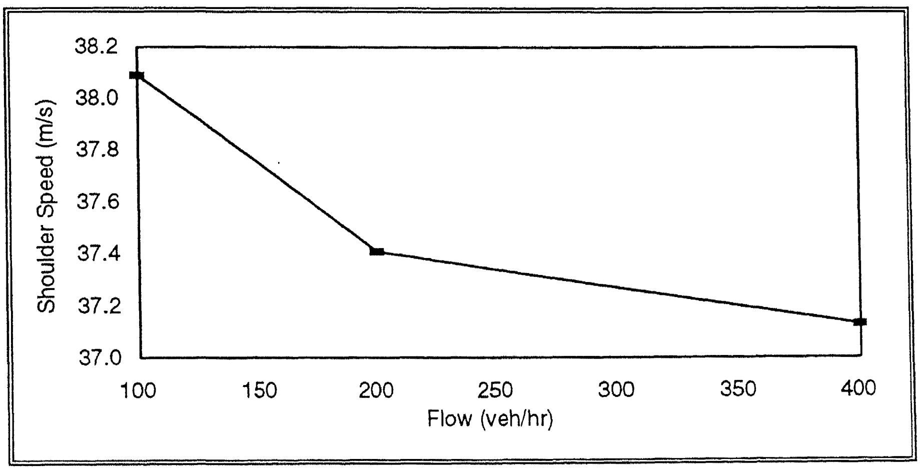


Fig 5.6 Average Shoulder Speed of Maruthi Car Stream

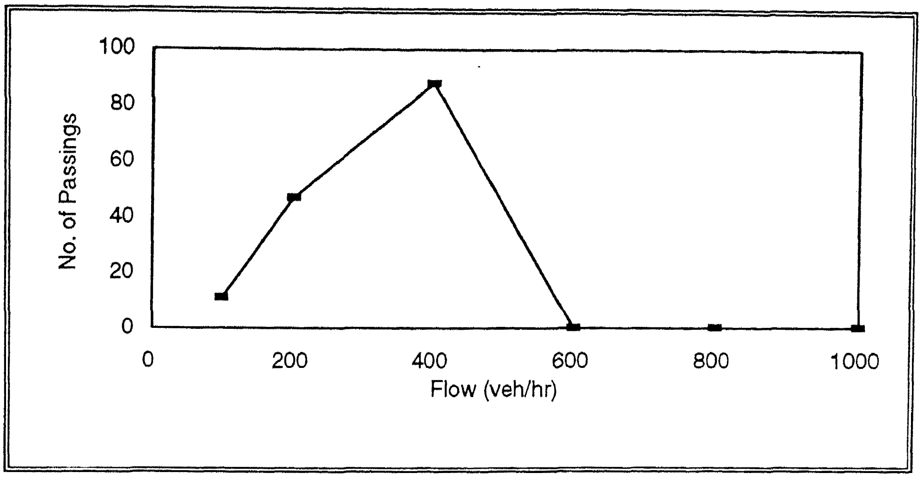


Fig 5.7 Number of Passings of Maruthi Car Stream

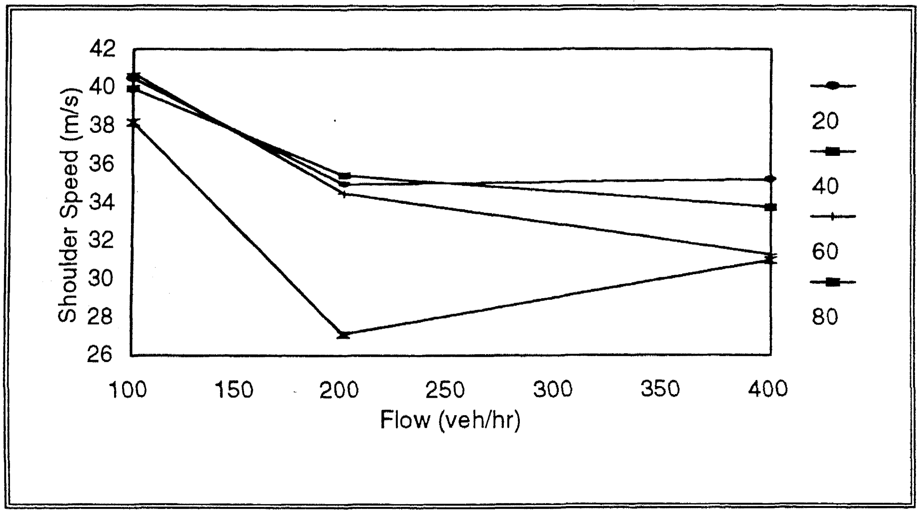


Fig 5.8a Average Shoulder Speed of Maruti in Maruti-Truck Car Stream

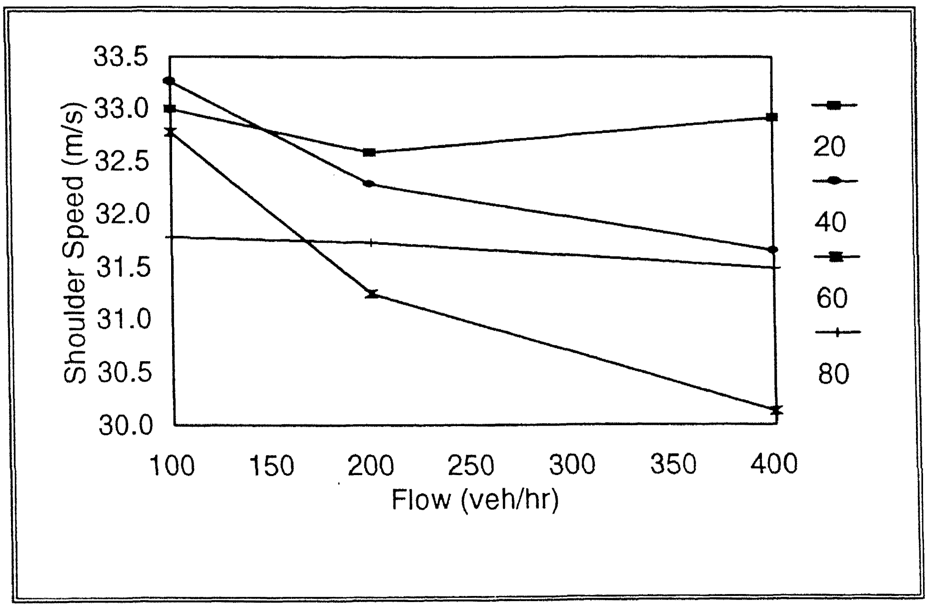


Fig 5.8b Average Shoulder Speed of Maruti in Maruti-Truck Car Stream

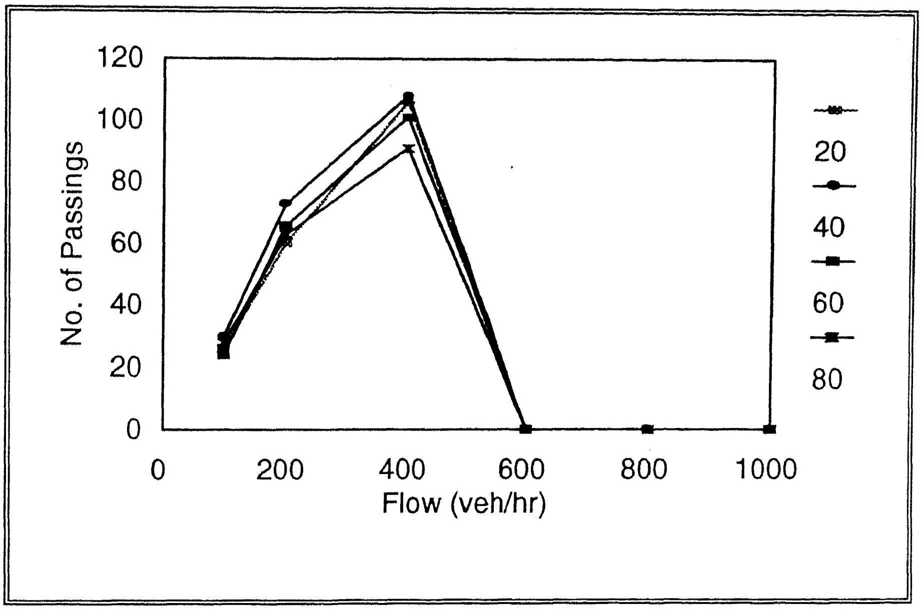


Fig 5.9 Number of Passings of Maruti-Truck Stream

5.4.3 Discussion on Results of Average Shoulder and Number of Passings

The passing operation, in case of both only Maruti Car stream and Maruti-Truck stream, occurs only upto a flow 600 veh/hr with maximum number of passing operation taking place at this flow. For higher flows there is hardly any passing operation. This is due to two reasons. Firstly, the flow is bidirectional and as flow increases the density increases, thereby reducing the availability of safe overtaking distance. Secondly, the tendency of the lead driver to yield decreases as the flow increases.

The average speed on the shoulder decreases as the flow increases. Also, the average speed on the shoulder decreases as the truck percentage in the stream increases. This is because the average speed of the stream itself decreases as the flow increases.

CHAPTER 6

Summary Conclusions and Scope for Further Study

6.1 Summary

The main objective of the present work is divided under four heads:

1. To identify the parameters affecting the simulation model and needing the most attention. Model sensitivity analysis has been carried out by varying most of the parameters and the effect of which is judged on the basis of their influence on the output.

2. To determine the PCE values of truck on a single lane plane terrain road using the method of Equivalent Vehicle Throughput.

3. To evaluate the level of service at various operating conditions on a bidirectional single lane plane terrain road using the Indo Swedish Traffic Simulation Model.

4. To study the acceleration noise, shoulder usage in the form of average shoulder speed and number of passings highlighting the use of simulation has to offer in all these circumstances.

To start with a list of parameters are identified for which sensitivity analysis is carried out. Road files corresponding to the different widths and terrain conditions are generated and are used for the entire sensitivity analysis. Traffic composition is decided depending on the parameter investigated and traffic files are generated corresponding to these road and traffic conditions. Simulation runs were performed for different flow rates and the output is processed to get the desired output format. The relative sensitivity of the model parameters is studied at different flow rates to conclude with the results of sensitivity analysis.

In the second stage, simulation runs were taken with only Maruti Car in the stream at various flow levels. The flow has been varied upto the anticipated capacity of the single

lane road. The composition of the stream is then changed by introducing trucks into the stream. The percentage composition of the trucks is varied from 20 % to 80 % in steps of 20 %.

In all the simulation runs, at each flow level, the characteristics of the traffic stream like the average speed, density, vehicle throughput, average shoulder speed, number of passings etc., are noted with the help of post processing programs. These results are then used to analyze Passenger Car Equivalents, capacity analysis, level of service conditions, study of acceleration noise and study of shoulder usage.

PCE values have been calculated for the truck using the concept of Equivalent Vehicle Throughput. Acceleration noise is also calculated for each of the simulation experiment to study the effect of each incremental addition of truck in Maruti car stream.

The level of service conditions are determined using the speed and density results. The variation in level of service with each increment of truck traffic has also been studied. Speed and density have been used as criteria for defining the level of service.

6.2 Conclusions

Following conclusions can be drawn from the results of sensitivity analysis:

1. Model is sensitive to the congestion effect (flow rates) and lane 3 probabilities. It is observed that the model for plane terrain roads is more sensitive to the lane 3 probabilities than the model for rolling terrain. Calibration of yield probabilities should be given atmost importance in the next stage of restructuring of the model. Sufficient data is to be collected to accomplish this task.

2. Sensitivity of the model to impedance due the presence of slow moving traffic has been established. It only indicates the significance of side friction in deciding the speed of the stream. Single lane road stretches are more prone to the adverse effects of impedance than intermediate lane road stretches.

3. Single lane road stretches are again more sensitive to the changes in deceleration rates. The reason for the increase of speeds on single lanes road is due to the higher number of interactions involved in this case which means that a vehicle has to decelerate many a times. Thus the higher deceleration rates allows the vehicle to slow down the vehicle in a shorter span of time. Thus on single lane plane terrain roads, the vehicles with higher deceleration rates can contribute to increase of speed of the traffic steam (at higher flow rates) .

4. It can be inferred that the Power weight ratios distribution and Basic Desired Speeds are not sensitive on its own due to the inconducive road and traffic conditions in the form of narrow widths and limiting speeds. Vehicles with higher power weight ratios and BDS do not have any real chance to accelerate and to overtake the slow moving vehicles due to the narrow widths and higher number of interactions. Thus it is worth while to study the effect of these factors on multi-lane road stretches where there is enough space for maneuvers.

5. Track 3 speed reduction factor is sensitive to changes and can be considered to detailed calibration depending on the speed of the vehicle when it decides to shift to track 3. Thus sufficient data is required to arrive at the these factors reflecting the slow and mixed traffic on Indian roads.

Following conclusions are drawn from the capacity and level of service analysis:

1. PCE of truck increases with flow level in a non linear manner. The PCE values are in a narrow range upto a flow rate of 400 veh/hr for all the composition of trucks. Beyond 400 veh/hr PCE values increases rapidly with the increase of flow. Again the increase is more pronounced at lower composition of trucks thus the addition of trucks to the traffic stream is effective only to an extent.

2. The peak of the acceleration noise curve shifts from right to left as the flow varies, indicating that the effect of adding truck, prevails for longer duration (in terms of percentage of truck) when the flow levels are less compared to higher flow levels.

The critical proportion of trucks, upper limit for the addition of trucks, above which more addition of them results in decrease in acceleration noise is less than 20 %.

3. The level of service drops drastically as the proportion of trucks increases in the traffic stream.

4. The average speed on the shoulder decreases with increase of flow and increase of percentage trucks in the stream due to the increase number of passings forcing the usage of shoulder. The shoulder usage in passing maneuver is only upto a flow of about 600 veh/hr where the usage is maximum. Also the shoulder usage decreases with the increase of percentage of trucks in the stream.

5. The results prove the versatility of the simulation model and indicate the advantages it can offer in understanding the traffic behavior and for data collection. With the help of the simulation model it is possible to measure the traffic parameters such as density and acceleration noise, which otherwise are extremely difficult to obtain in the field.

6.3 Scope for Further Studies

There has been very little work done in this field of capacity and level of service analysis so far in India. Further work can be carried out in the following areas.

1. Calibration of yield probabilities and track 3 speed reduction factors can be considered in the next stage of restructuring of the model. Sufficient data is to be collected to accomplish this task.

2. The adjustment factors needed for obtaining capacity at prevailing conditions can be studied. Adjustment factors can be calculated for

   - Reduction in capacity due to reduction in shoulder width
   - Reduction in capacity due to soft and poor shoulders compared to hard and good shoulders

- Reduction in capacity due to the presence of heavy and slow moving vehicles
- Reduction in capacity due to curvature, grade, and roughness.
- Reduction in capacity for non-ideal directional distribution (i.e., other than 50/50 distribution) of traffic etc.,

3. Similar studies can be conducted for analyzing the capacity on two lane and multi lane highways.

4. The variation of Passenger Car Equivalents for heavy vehicles on specified grades can be studied.

5. A beginning can be made for the formulation of an Indian Highway Capacity Manual after analyzing capacity on all the types of highway facilities. The Indo Swedish Traffic Simulation Model can be used as an efficient tool for such an endeavor as indicated by the present work.

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